PROFESSIONAL PAPER OF THE SIGNAL CORPS, U. S. ARMY

MULTIPLEX TELEPHONY AND TELEGRAPHY

BY MEANS OF ELECTRIC WAVES GUIDED BY WIRES

WASHINGTON
GOVERNMENT PRINTING OFFICE
1911

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BY MEANS OF ELECTRIC WAVES GUIDED BY WIRES

BY

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1911

WAR DEPARTMENT,

Document No. 390.

OFFICE OF THE CHIEF SIGNAL OFFICER.

War Department,
Office of the Chief of Staff,
Washington, March 29, 1911.

The following report on "Multiplex Telephony and Telegraphy by Means of Electric Waves Guided by Wires," prepared in the office of the Chief Signal Officer of the Army by Maj. George O. Squier, Signal Corps, is published as a professional paper of the Signal Corps for the information of the Regular Army and the Organized Militia.

By direction of the Secretary of War:

Leonard Wood,
Major General, Chief of Staff.

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MULTIPLEX TELEPHONY AND TELEGRAPHY BY MEANS OF ELECTRIC WAVES GUIDED BY WIRES.

I. INTRODUCTION.

Electrical transmission of intelligence, so vital to the progress of civilization, has taken a development at present into telephony and telegraphy over metallic wires; and telegraphy and, to a limited extent, telephony, through the medium of the ether by means of electric waves.

During the past 12 years the achievements of wireless telegraphy have been truly marvelous. From an engineering viewpoint, the wonder of it all is that, with the transmitting energy being radiated out over the surface of the earth in all directions, enough of this energy is delivered at a single point on the circumference of a circle, of which the transmitting antenna is approximately the center, to operate successfully suitable receiving devices by which the electromagnetic waves are translated into intelligence.

The "plant efficiency" for electrical energy in the best types of wireless stations yet produced is so low that there can be no comparison between it and that of the least efficient transmission of energy by conducting wires.

The limits of audibility, being a physiological function, are well known to vary considerably, but they may be taken to be in the neighborhood of 16 complete cycles per second as the lower limit and 15,000 to 20,000 cycles per second as the upper limit. If, therefore, we could impress upon a wire circuit for transmitting intelligence harmonic electromotive forces of frequencies between 0 and 16 cycles per second, or, again, above 15,000 to 20,000 cycles per second, we would be assured that whatever effects such electric-wave frequencies produced upon metallic lines, the present apparatus employed in operating them could not translate this effect into audible signals.

There are, therefore, two possible solutions to the problem of multiplex telephony and telegraphy upon this principle by electric waves, based upon the unalterable characteristic of the human ear, viz, by employing (1) electric waves of infra-sound frequencies, and (2) those of ultra-sound frequencies. One great difficulty is in designing generators of infra-sound frequencies giving a pure sine wave, as otherwise any harmonic of the fundamental would appear within the range of audition. Furthermore, the range of frequencies is restricted, and the physical dimensions of the tuning elements for such low frequencies would have a tendency to become unwieldy.

The electromagnetic spectrum at present extends from about four to eight periods per second, such as are employed upon ocean cables, to the shortest waves of ultra-violet light. In this whole range of frequencies there are two distinct intervals which have not as yet been used, viz, frequencies from about 3×10^{12} of the extreme infra-red to 5×10^{10}, which are the shortest electric waves yet produced by electrical apparatus, and from about 80,000 to 100,000 cycles per second to about 15,000 to 20,000 cycles per second. The upper limit of this latter interval represents about the lowest frequencies yet employed for long distance wireless telegraphy.

Within the past few years generators have been developed in the United States giving an output of 2 kilowatts and more at periods of 100,000 cycles per second, and also capable of being operated satisfactorily at as low a frequency as 20,000 cycles per second. Furthermore, these machines give a practically pure sine wave.

The necessary condition for telephony by electric waves guided by wires is an uninterrupted source of sustained oscillations, and some form of receiving device which is quantitative in its action. In the experiments described in multiplex telephony and telegraphy it has been necessary and sufficient to combine the present engineering practice of wire telephony and telegraphy with the engineering practice of wireless telephony and telegraphy.

The frequencies involved in telephony over wires do not exceed 1,800 to 2,000, and for such frequencies the telephonic currents are fairly well distributed throughout the cross section of the conductor. As the frequency is increased the so-called skin effect becomes noticeable, and the energy is more and more transmitted in the ether surrounding the conductor.

It has been found possible to superimpose, upon the ordinary telephonic wire circuits now commercially used, electric waves of ultra-sound frequencies without producing any harmful effects upon the operation of the existing telephonic service. Fortunately, therefore, the experiments described below are constructive and additive, rather than destructive and supplantive.

Electric waves of ultra-sound frequencies are guided by means of wires of an existing commercial installation and are made the vehicle for the transmission of additional telephonic and telegraphic messages.

APPARATUS AND EQUIPMENT.

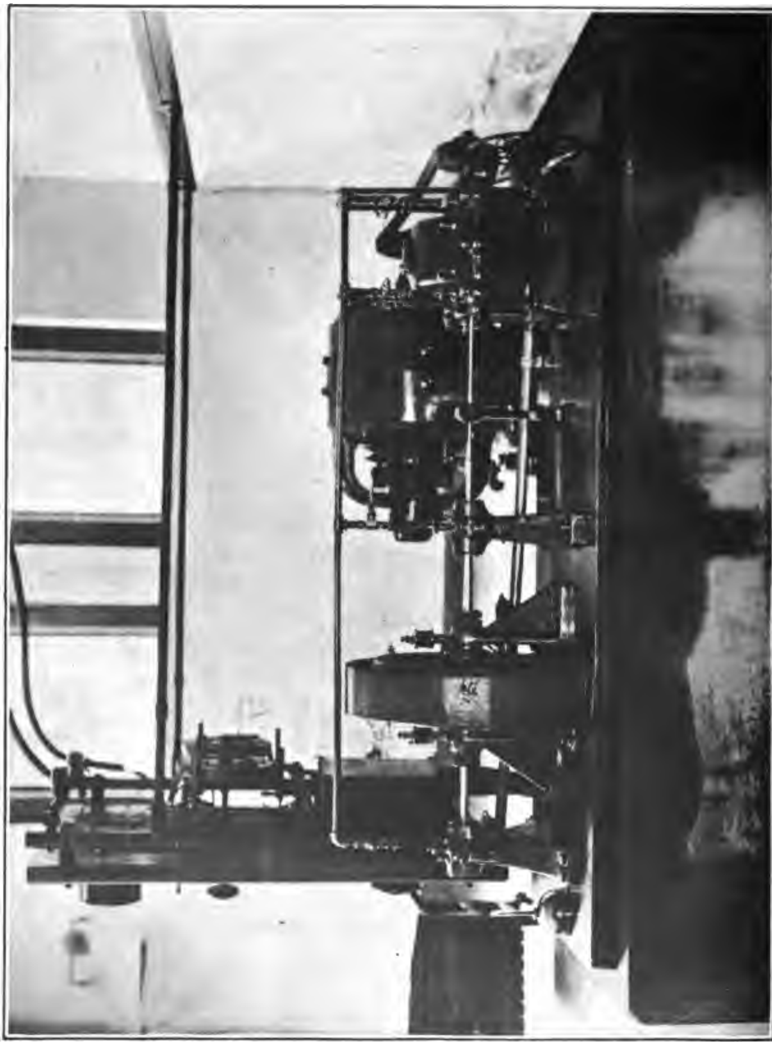
Under a special appropriation granted to the Signal Corps by Congress in the Army appropriation act of 1909, a small research laboratory has been established at the Bureau of Standards, in the suburbs of the city of Washington. This laboratory is equipped with the latest forms of apparatus now employed in the wireless telephone and telegraph art, and also with the standard types of telephone and telegraph apparatus now used upon wire circuits. The small construction laboratory of the United States Signal Corps is located at 1710 Pennsylvania Avenue and is also equipped with the usual types and forms of apparatus used in transmitting intelligence by electrical means. Each of these laboratories is supplied with a wireless telephone and telegraph installation with suitable antennæ. In addition, these two laboratories are connected by a standard telephone cable line about 7 miles in length, which was employed in the experiments described below.

THE 100,000-CYCLE GENERATOR.

The high-frequency alternator, which is shown complete with driving motor and switchboard in the accompanying photographs, is a special form of the inductor type designed for a frequency of 100,000 cycles with an output of 2 kilowatts, making it adapted for use in wireless telephony or telegraphy.

DRIVING MOTOR.

The motor is a shunt-wound 10-horsepower machine with a normal speed of 1,250 revolutions per minute. It is connected by a chain drive to an intermediate shaft which runs

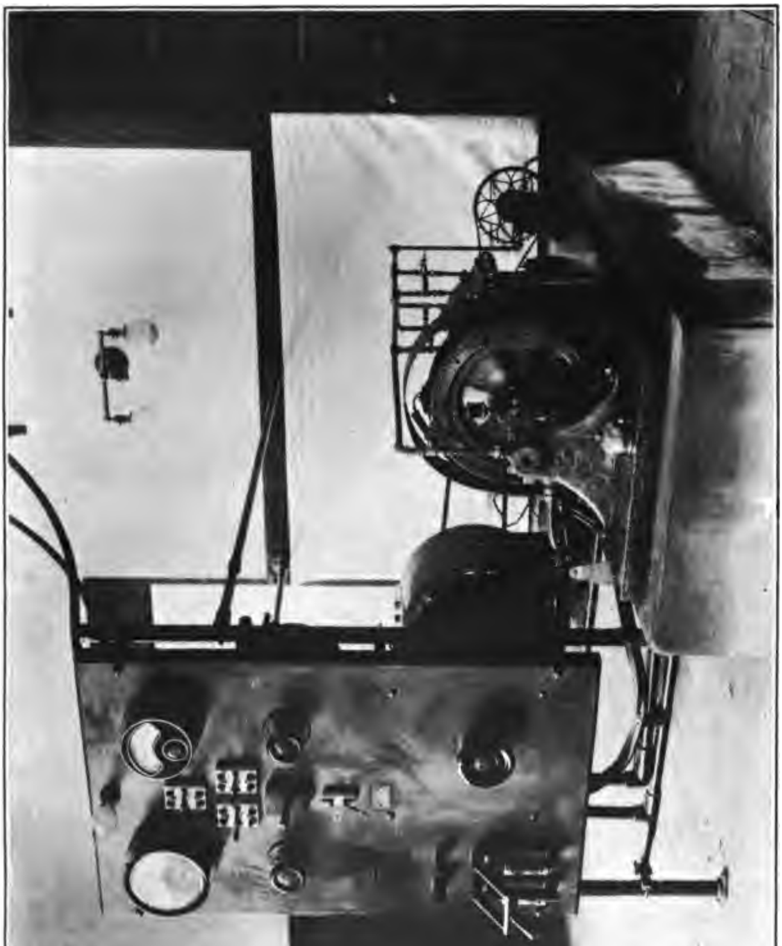


High frequency alternator.

at a speed of 2,000 revolutions per minute. The intermediate shaft drives the flexible shaft of the alternator through a De Laval turbine gearing, having a ratio of 10 to 1. The flexible shaft and inductor thus revolve at a speed of 20,000 revolutions per minute.

FIELD COILS.

The field coils, mounted on the stationary iron frame of the alternator, surround the periphery of the inductor.



Switchboard high frequency alternator.

The magnetic flux produced by these coils passes through the laminated armature and armature coils, the air gap, and the inductor. This flux is periodically decreased by the nonmagnetic sections of phosphor bronze embedded radially in the inductor at its periphery.

ARMATURE COILS.

The armatures or stators are ring shaped and are made of laminated iron. Six hundred slots are cut on the radial face of each; a quadruple silk-covered copper wire, 0.016 of an inch in diameter, is wound in a continuous wave up and down the successive slots. The peripheries of the armature frames are threaded to screw into the iron frame of the alternator. By means of a graduated scale on the alternator frame the armatures can be readily adjusted for any desired air gap.

INDUCTOR.

The inductor or rotor has 300 teeth on each side of its periphery, spaced 0.125 of an inch between centers. The spaces between the teeth are filled with U-shaped phosphor-bronze wires, securely anchored, so as to withstand the centrifugal force of 80 pounds exerted by each. Since each tooth of the inductor gives a complete cycle, 100,000 cycles per second are developed at 20,000 revolutions per minute. The diameter of the disk being 1 foot, the peripheral speed is 1,047 feet per second, or 700 miles per hour, at which rate it would roll from the United States to Europe in four hours. By careful design and selection of material, a factor of safety of 6.7 is obtained in the disk, although the centrifugal force at its periphery is 68,000 times the weight of the metal there.

BEARINGS.

The generator has two sets of bearings, as shown in the photographs, the outer set being the main bearings which support the weight of the revolving parts. These bearings are self-aligning and are fitted with special sleeves, which are ground to coincide with longitudinal corrugations of the shaft, thus taking up the end thrust. A pump maintains a continuous stream of oil through these bearings, allowing the machine to be run continuously at full speed without troublesome heating.

The middle bearings normally do not touch the shaft, but take up excessive end thrust and prevent excessive radial vibration of the flexible shaft.

An auxiliary bearing or guide is placed midway between the gear box and the end bearing. Its function is to limit the vibration of that portion of the shaft.

CRITICAL PERIODS.

In starting the machine, severe vibration occurs at two distinct critical speeds, one at about 1,700 and the other at about 9,000 revolutions per minute. The middle bearings prevent this vibration from becoming dangerous.

VOLTAGE.

With the normal air gap between the armatures and revolving disk of 0.015 inch, the potential developed is 150 volts with the armatures connected in series. It is possible, however, to decrease the air gap to 0.004 of an inch for short runs, which gives a corresponding increase in voltage up to nearly 300 volts. It is considered inadvisable, however, to run with this smaller air gap for any great length of time.

The machine is intended to be used with a condenser, the capacity reactance of which balances the armature inductance reactance, which is 5.4 ohms at 100,000 cycles. This would require a capacity of about 0.3 microfarad for resonance at this frequency, but in the experiments conducted at 100,000 cycles it was found necessary to decrease this amount on account of the fixed auxiliary inductance of the leads.

CONSTANTS OF THE TELEPHONE LINE.

The telephone line used in these experiments extends from the Signal Corps laboratory at 1710 Pennsylvania Avenue to the Signal Corps research laboratory at the Bureau of Standards.

This line is made up of the standard commercial equipment and consists of paper-insulated twisted pairs in lead-covered cable, placed in conduit in the usual manner employed for city installation. For the sake of convenience, one of the pair is designated as No. 1 wire and the other as No. 2 wire.

The air-line distance between the two laboratories is a little over 3 miles, but the telephone line, by passing through three exchanges, covers about 7 miles. The course of the line, with the size and type of conductor, is as follows:

Laboratory, 1710 Pennsylvania Avenue, to main exchange, underground cable, No. 22 B. & S.

Main exchange to west exchange, underground cable, No. 19 B. & S.

West exchange to Cleveland exchange, underground cable, No. 19 B. & S.

Cleveland exchange to Bureau of Standards, underground cable, No. 19 B. & S.

All underground cable, except from Bureau of Standards to Wisconsin Avenue and Pierce Mill Road, about 3,400 feet, which is aerial cable.

This line is equipped with protective heat coils of a standard type, one in each wire of the metallic circuit, at the Cleveland exchange and the main exchange, but none at the west exchange. The constants of each of these coils are as follows:

Direct current resistance of 65° F., 3.8 ohms.

Size of wire, No. 30 B. S.

Length of wire, 40 centimeters.

Number of turns in each coil, about 38.

Measured inductance at 70,000 cycles, 4,400 centimeters, or 4.4 x 10^{-6} henry.

The above constants were measured from a sample of one of these coils selected at random.

Resistance of metallic circuit, 776 ohms.

Capacity measured between No. 1 wire and No. 2 wire (one minute electrification), 0.69 microfarad.

Insulation resistance:

Between No. 1 wire and earth	megohms	0.9
Between No. 2 wire and earth	do	1.3
Between No. 1 and No. 2 wires in parallel and earth	do	0.8
Between No. 1 and No. 2 wires	do	2.1

The line included the usual house wiring at each station, which was undisturbed in taking the measurements.

II. DUPLEX-DIPLEX TELEPHONY OVER WIRE CIRCUITS.

Such has been the development of telephone engineering that at present any proposal which requires for its success the supplanting of the present low-frequency battery system would be most radical. It would surely be admitted that any plan which permits the present telephone system to remain intact and superimposes thereon additional telephone circuits would possess cardinal advantages. Accordingly, the first preliminary experiments were directed to the inquiry as to whether or not it is possible to superimpose upon the minute telephonic currents now employed in telephony over wires, electric waves of ultra-sound frequencies without causing prohibitive interference with the battery telephone currents. Manifestly, we can best determine this fundamental point by experiments, at the generator itself, with the most sensitive part of the telephone equipment, viz, the telephone receiver. Accordingly, experiments were first conducted with various forms and types of telephone receivers in connection with local circuits at the generator. Such is the sensibility of the telephone receiver that it was thought possible that, although currents of frequencies entirely above audition were applied to the receiver from a dynamo as a source, there might be some frequency or frequencies from the operation of the apparatus which would be within the range of audition. Such was found, in fact, to be the case at certain critical frequencies of the machine, but they were of no practical importance, as will be shown later.

With a collection of telephone receivers ranging from about 50 to over 8,000 ohms resistance and of a variety of design, a series of tests was made under severe conditions to determine the above point. It was found, in general, that alternating currents of frequencies ranging from 20,000 to 100,000 complete cycles per second, when coupled directly, inductively, or electrostatically to local circuits from the generator produced absolutely no perceptible physiological effects in the receivers, excepting only that at certain of the higher frequencies a distinct audible note was heard.

A search for the cause of this note showed that it is due to a slight periodic variation of the amplitude of the high frequency current of the generator, since no evidence of it could be detected on the battery telephone side of the circuit. It appears to be caused by a very slight vibration of the rotor as a whole in the magnetic field of the generator. It was almost entirely removed by the simple device of opening out the stators, which increases the clearance and materially cuts down the flux of the machine. In practice it is a distinct advantage, however, to have a trace of this note still left on the high frequency side of the circuit; otherwise there is no ready means of determining at the receiving end of the cable line whether or not the high frequency current is present on the line, whereas this note, which had to be searched for in tuning and which was entirely tuned out when speech was best, gave a very convenient method of testing for the presence of high frequency current.

Having determined the general nature of this disturbance and its comparative unimportance, no further investigation of it was considered necessary at that time.

The next fundamental point to determine was whether or not at these frequencies a telephone can receive enough energy to make it operative for producing sound waves in air.

Since the self-induction of a standard telephone receiver is high, energy at these frequencies is effectively barred from it. In the wireless telegraph art, where the frequencies involved are from 100,000 to several million per second, this problem has been uniformly solved by the introduction of some form of detector for electromagnetic waves, whose function is to transform the energy of the high frequency oscillations into other forms suitable to a type of instrument such as a telephone receiver.

The next step, therefore, consisted in introducing various forms of detectors, such as are now used in wireless telegraphy, between the telephone receiver itself and the energizing circuit. Since the frequencies being here considered are entirely above audition it was necessary, in order to produce a physiological effect, to introduce another element in this transformation, viz, some method of modifying the continuous train of sustained oscillations from the generator into groups or trains, the period of which falls within the limits of audition. This was accomplished by employing the regular forms of automatic interrupters, such as are now used in wireless telegraphy, with the expected result that with these two additional and essential pieces of apparatus operatively connected between the telephone receiver and the generator the energy of the generator was delivered to the ear in a form well suited for physiological effects. Since it is well known that the human ear is most sensitive at a period of about 500 cycles per second, or 1,000 alternations, interrupters giving this frequency were employed.

The presence of the detectors in this chain of transformations is necessitated by the use of the telephone receiver as a translating device.

Although some of the detectors for electric waves are very sensitive to electrical energy they are here employed not because they are more sensitive to electrical energy than is the telephone receiver itself, which is not the case, but because the telephone receiver is not adapted, for the reasons stated above, to translate electrical energy of these frequencies into movements of its diaphragm.

The elements of the apparatus thus far include a generator of sustained high-frequency oscillations, an interrupter to modify the amplitude of these oscillations into groups of a period within the range of audition, some form of detector to rectify these oscillations, and a telephone receiver. Manifestly we have here all of the elements that are necessary for telegraphy, using the telephone receiver to interpret the signals.

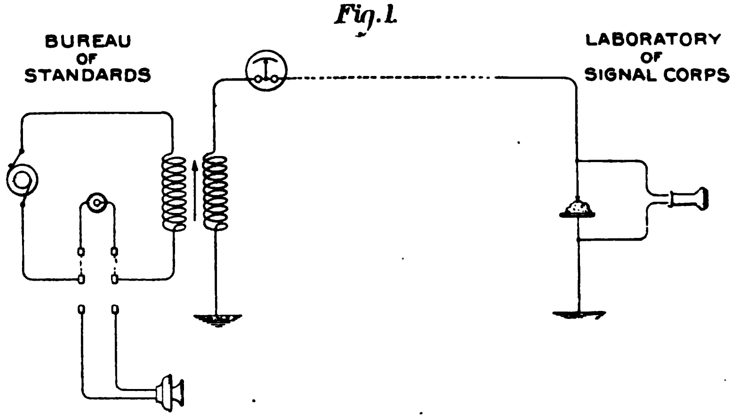
If in the above-mentioned chain of apparatus we replace the interrupter by some form of telephone transmitter, such as the microphone, we have all that is necessary for the transmission of speech.

Experiments were made over local circuits with apparatus arranged in this order over a range of frequencies from 20,000 to 100,000, with the result that speech was transmitted very satisfactorily. Upon removing the detector from the above arrangement all perceptible effect in the telephone receiver ceased; in fact, no arrangement of connections of a telephone receiver to such a high-frequency circuit which did not include some form of detector was found to be operative for telephony, unless certain low-resistance telephones were used, in which case the speech was so much weaker as to be of entirely different order of magnitude.

The presence of a detector in this chain of operations is not absolutely necessary in the case of telegraphy, since if the interrupter automatically produces a definite number of wave trains per second, each train consisting of at least several complete oscillations, an effect may be produced upon a telephone receiver directly without a detector. The physiological effect, however, is quite different, the clear fundamental note corresponding to the frequency of the interrupter being no longer audible, but, instead, a peculiar dull hissing sound. If, however, a telephone receiver was used which had a core of soft iron instead of a permanent magnet, no effect without the detector was produced with the energy used. As stated above in the case of telephony, the energy required for telegraphy without a detector is of a far greater order of magnitude than when a detector is employed.

Having determined the necessary and sufficient conditions for the accomplishment of telegraphy and telephony by means of electric waves guided by wires upon local circuits, the next step was to apply these means and condi-

Fig. 1.



tions to an actual commercial telephone cable line, the constants of which have been given above.

The machine was run at a frequency of 100,000 cycles per second with the circuit arrangements as shown in figure 1, where one wire of the telephone cable was connected to one terminal of the secondary of an air-core transformer, the other terminal being connected to earth. At the receiving end of the line, which was the Signal Corps construction laboratory, at 1710 Pennsylvania Avenue, Washington, D. C., this wire was connected directly to earth through a "perikon" crystal detector, such as is well known in wireless telegraphy, and a high resistance telephone receiver of about 8,000 ohms was shunted around the crystal. In this preliminary experiment no attempt was made at tuning, either at the transmitting end or at the receiving end of the line.

In the primary circuit of the generator arrangements were made by which either an interrupter and telegraph key or a telephone transmitter could be inserted by throwing a switch.

In the line circuit a hot-wire milliammeter was inserted in a convenient position, so that the effect of the operation of either the telegraph key or of the human voice upon the transmitter could be observed by watching the fluctuations of the needle of the milliammeter.

A loose coupling was employed between the two circuits at the transmitting end and the line circuit adjusted by varying the coupling until the current in the line was 20 to 30 milliamperes. With this arrangement (1) telegraphic signals were sent and easily received, and (2) speech was transmitted and received successfully over this single wire with ground return.

The ammeter showed marked fluctuations from the human voice and enabled the operator at the transmitting station to be certain that modified electric waves were being transmitted over the line.

The actual ohmic resistance of the line apparently played an unimportant part for telegraphy at 100,000 cycles, since with one of the wires of the pair and a ground return the effect of doubling the conductivity of the wire by joining both wires in parallel, although this arrangement increased the capacity of the wires, could not be detected with certainty by an operator listening to the signals and unaware of which arrangement was being used.

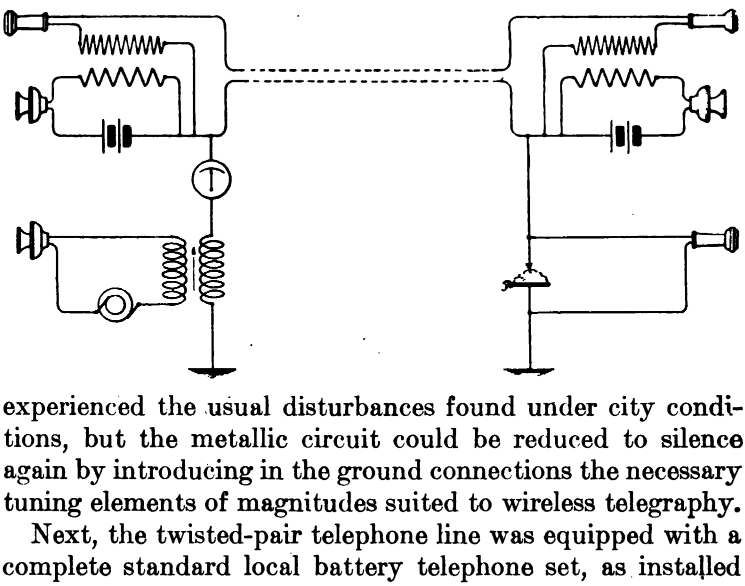
Inserting in the line wire a noninductive carbon rod resistance of 750 ohms, which is practically the resistance of the line itself, could not be detected by any change in the intensity of the received signals.

The next experiment was to determine what effect, if any, such sustained electrical oscillations would have upon the minute telephonic currents employed in battery telephony.

DUPLEX TELEPHONY, USING ONE GROUNDED CIRCUIT.

To determine the fact that electric waves of ultra-sound frequency produce no perceptible effect when superimposed on the same circuit over which telephonic conversation is being transmitted, the next step was to use such a train of sustained oscillations as the vehicle for transmitting additional speech over the same circuit. For this purpose the twisted-pair telephone line was equipped with a complete standard local battery telephone set, as installed for commercial practice, and in addition one of the wires of the pair was equipped as in figure 1, the circuit being shown diagrammatically in figure 2. This particular arrangement was employed in this experiment for the reason that it was desired to have the battery telephone operate on its usual circuit with the introduction of ground connections at the ends of the line for the superposition of the high frequency circuit. When such ground connections were introduced directly without tuning elements therein the metallic circuit

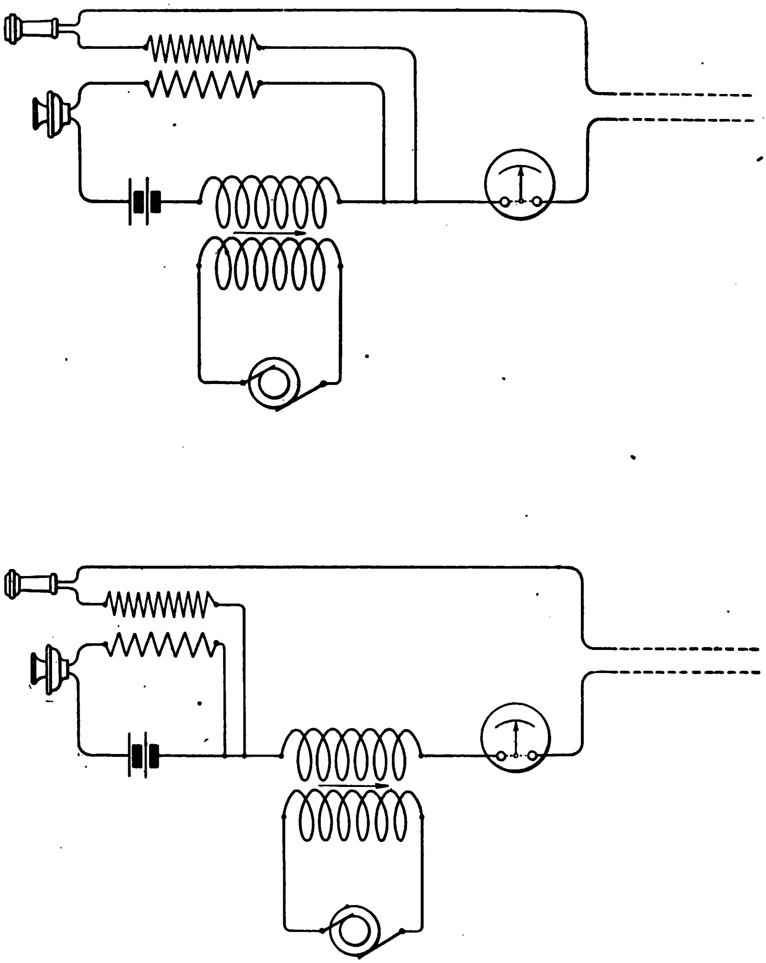
Fig. 2.



experienced the usual disturbances found under city conditions, but the metallic circuit could be reduced to silence again by introducing in the ground connections the necessary tuning elements of magnitudes suited to wireless telegraphy.

Next, the twisted-pair telephone line was equipped with a complete standard local battery telephone set, as installed for commercial practice, with the exception that the local battery circuit of the transmitter telephone set was opened and a few turns of coarse wire inserted in series with the two dry cells which are normally used, as shown in figure 3. Inductively connected with this coil was the armature circuit of the generator. A hot-wire milliammeter was placed in the line circuit to indicate the magnitude of the high frequency current which was flowing on the line. With this arrangement tests were made to determine whether or not there were any effects upon the transmission of speech, due to superimposing high frequency currents upon the battery telephone sets. With an operator at each end of the line,

Fig. 3.



using the equipment in the regular commercial way, the direct-current voltage and the alternating-current voltage in series with it in the primary circuit of the transmitter were varied individually and relatively in a variety of ways, with the striking result that just at the point where the direct-current voltage was decreased so that no sounds were received from it the line became absolutely silent, although the alternating voltage in the circuit was at its largest value, or, again, speech would reappear at the receiving station at the moment when sufficient direct-current voltage was introduced to produce it, and the simultaneous presence of both the maximum direct voltage and maximum high frequency voltage in a circuit produced exactly the same result as the maximum direct current voltage did alone. When, however, the high frequency current in the local circuit was forced to a point which caused "burning" in the transmitter itself, then, and then only, did the high frequency current in any way interfere with the transmission.

By transferring this coil from the local circuit of the telephone set directly into the line itself, so that the high-frequency oscillations would be superimposed upon the line beyond the iron-cored induction coil of the telephone transmitter, it was not possible to detect the presence or absence of high-frequency currents.

As a test under severest conditions the effect was noted upon speech received at the same station at which the high-frequency current is being impressed, for here are the attenuated telephonic currents at the receiving end of the telephone line, on which is superimposed a high-frequency current of vastly greater magnitude at the same point. No effects of any kind could be detected under these conditions. From the above experiments it appears that in any attempt at multiplex telephony by means of electric waves of ultra-sound frequencies superimposed upon the minute telephonic currents employed in battery transmission there is nothing to fear from disturbances of such currents upon the operation of the ordinary battery equipment.

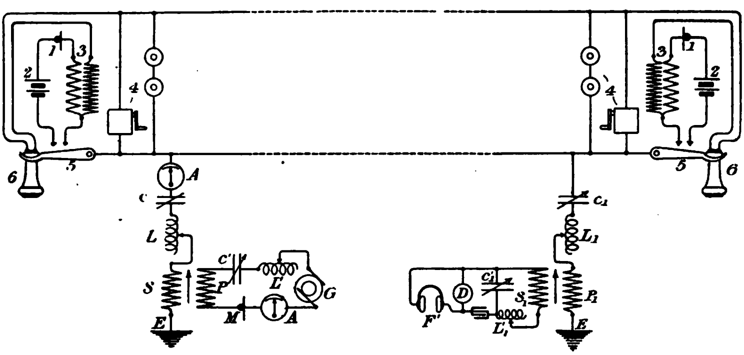
SILENT EARTH CIRCUITS.

The electromagnetic constants of the apparatus employed in telegraphy and telephony over wire circuits are of the order of magnitude of microfarads and henrys, and since no attempt is made at tuning, these are constructed at present with no provision for continuously varying the units.

In wireless telegraphy and telephony these electromagnetic constants are of the order of magnitude 1,000 times smaller, or are expressed in thousandths of microfarads and of henrys; furthermore, these forms of apparatus are provided with convenient means of continuously varying their values for tuning.

In the operation of providing tuning elements for earth connections there is afforded at the same time a certain means of eliminating any harmful disturbances from the earth, for the condensers employed for tuning to frequencies above audition possess an impedance to the frequencies involved in speech and also any disturbances from the earth which effectively prevents the passage of any disturbance of audible frequency. These condensers offer a comparatively free passage to the electrical oscillations of the frequencies here

Fig. 4.



being considered. When such earth connections are selectively tuned with the line to frequencies entirely above audition it is evident that no audible frequencies, either in the earth itself or from the line, can pass. Simple experiments proved the efficiency of this arrangement, and when the metallic telephone circuit, equipped with a standard local battery set, was connected to earth in the manner described, the operation of the battery set was perfectly quiet and equally good with and without such earth connections.

The point was now reached where the road was clear for duplex telephony, and for this purpose the apparatus and methods employed in wireless telephony were applied to one of the wires of the metallic circuit as though it were an antenna. The actual arrangement of this circuit is shown in figure 4, in which G is the source of sustained high-frequency oscillations; C′ is the tuning condenser of the oscillatory circuit; L′ is the tuning inductance of the oscillatory circuit; P is the primary of the oscillation transformer; A is the ammeter; M is the transmitter microphone; S is the secondary of the oscillation transformer in the line circuit; C is the tuning condenser in the line circuit; L is the tuning inductance in the line circuit; A′ is the ammeter in the line. At the receiving end of the line C_1 is the line-tuning condenser. L_1 is the line-tuning inductance; P_1 is the primary of the oscillation transformer; S_1 is the secondary of the oscillation transformer; L'_1 is the tuning inductance in the oscillatory circuit; C'_1 is the tuning condenser in the oscillatory circuit, between which and the telephone F′ the detector D is operatively connected; E is the earth connection.

The local battery telephone sets are connected across the two line wires in the usual manner. In both sets 1 is the microphone transmitter; 2 is the local battery; 3 is the induction coil; 4 is the ringing system, including the bell and hand generator; 5 is the switch hook; 6 is the telephone receiver.

The detector employed was the audion, of the so-called vacuum type, consists of an exhausted bulb containing (*a*) a tungsten filament maintained at incandescence by a current from a local battery of 6 volts and (*b*) 2 platinum electrodes insulated from the filament and from each other. To these electrodes, one of which is a platinum plate and the other a platinum grid, there are applied through the high-resistance receivers about 35 to 45 volts from a local battery. The brilliancy of the filament is controlled by a small series rheostat, and the voltage applied to the insulated terminals by a local potentiometer.

The gases in the bulb, becoming ionized by contact with the glowing electrode, serve as a conductor of electricity, having a high unilateral conductivity. If the platinum wire grid is close to the hot filament and the plate at some greater distance, the direction of greater conductivity is from the plate through the gas by the ionic path to the grid, so that if the positive terminal of the telephone battery is applied at the plate terminal and the negative at the grid terminal, a sufficient current to operate the telephone will flow.

If the terminals of the condenser of a resonant receiving circuit are connected to the grid and one terminal of the filament, the high frequency electromotive force impressed from this resonant circuit will cause a greater current to flow through the gas in one direction than in the other, as in the case of the direct current potential applied through the telephone receiver. This rectifying effect will be reproduced in the telephone receivers, causing them to make audible the received signals.

By changing the coefficient of coupling or the potential across the audion, which is adjustable, or the amount of ionization of the gases in the tube by adjusting the current through the filament, or any combination of these, it was found that the receiving operator could bring out the speech to suit his particular fancy.

It was found that cross-talk was heard in the audion circuit from the battery transmitter at the transmitting end when the audion circuit alone was connected directly to earth from the line without any tuning coil or condenser. If, however, the tuning condenser was inserted, this cross-talk entirely disappeared, even though the tuning coil was not inserted. This is because the impedance of the small tuning condenser is large for telephonic frequencies, while the tuning coil impedance admits these telephonic frequencies. Both elements of tuning are required for selective absorption of energy, so that the high-frequency circuit is available as an additional telephonic circuit. With this arrangement talking in the transmitter of the high-frequency side of the system was heard only in the audion, there being no effect of the high-frequency transmission on the local battery transmission and there was no cross-talk from the ordinary local battery circuit; the two telephonic messages were completely separated. Both circuits were entirely free from earth disturbances.

The volume of speech at the receiving end of the cable is greatly increased by the simple device of inserting the transmitter in the dynamo circuit and operating this circuit at or near resonance. In addition, the coupling at both transmitting and receiving stations should be so designed as to permit adjustment for optimum.

The frequency used in this experiment was about 100,000 cycles per second. The talk on the regular battery circuit was of the usual high standard both ways, so that the only reason at this point why complete duplex-diplex telephony was not obtained was the fact that there was no high-frequency dynamo available at the laboratory, 1710 Pennsylvania Avenue. There is, however, available at this laboratory one of the latest forms of the high-frequency arc, and accordingly this was arranged with suitable electromagnetic constants to give a period of about 71,000 cycles per second, as measured by a standard wave meter, such as is now commonly used in wireless telephony and telegraphy. This source of high-frequency electromotive force was induced upon the high-frequency line wire in a similar manner to that described in the station at the Bureau of Standards, with the result that one of the wires of the twisted pair was made to carry simultaneously the battery telephonic currents from the two transmitters, the high-frequency oscillations of about 100,000 cycles per second, applied at the Bureau of Standards, and the high-frequency oscillations of about 71,000 cycles per second, applied at 1710 Pennsylvania Avenue. No influence from these conditions was perceptible upon the excellence of the battery transmission and reception of speech either way.

DUPLEX TELEPHONY, USING METALLIC CIRCUIT.

(*a*) BRIDGING ARRANGEMENT.

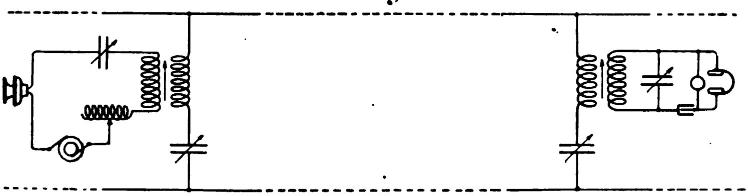
The next experiments pertained to the standard metallic circuit as universally used on telephone toll lines in congested districts. The electric constants of this line have already been given.

The next step was to remove entirely the earth connections from the metallic circuit and superimpose both telephonic circuits upon the same pair of wires, as shown in figure 6, in which the high-frequency apparatus, shown diagramatically in figure 5, is bridged across the line wires A and A′. G is the source of sustained high-frequency oscillations; C_1 is the tuning condenser of the oscillatory circuit; L_1 is the tuning coil of the oscillatory circuit; P is the primary of the oscillation transformer; A is the ammeter; M is the transmitter microphone; S is the secondary of the oscillation transformer in the line circuit; C is the tuning condenser in the line circuit; L is the tuning inductance in the line circuit;

A_1 is the ammeter in the line. At the receiving end of the line, C′ is the line tuning condenser; L′ is the line tuning inductance; P′ is the primary of the oscillation transformer; S′ is the secondary of the oscillation transformer; L″ is the tuning inductance in the oscillatory circuit; C″ is the tuning condenser in the oscillatory circuit, between which and the telephone F the detector D is operatively connected.

The local battery telephone sets are connected across the line wires in the usual manner. In both sets, 1 is the micro-

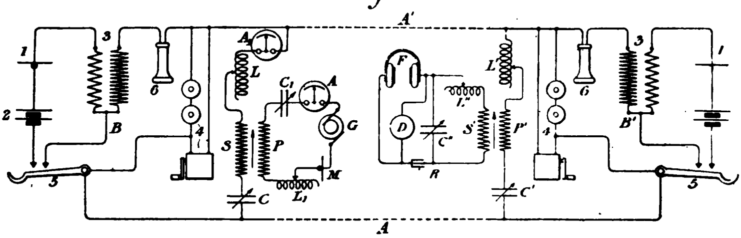
Fig. 5.



phone transmitter; 2 is the local battery; 3 is the induction coil; 4 is the ringing system, including the bell and hand generator; 5 is the switch hook; 6 is the telephone receiver.

Since the high-frequency apparatus as commercially developed in the wireless telegraph art was used, each of the units was variable and had been previously carefully calibrated by reference to the standards of the Bureau of Standards. The coupling coils were of the design adapted

Fig. 6.

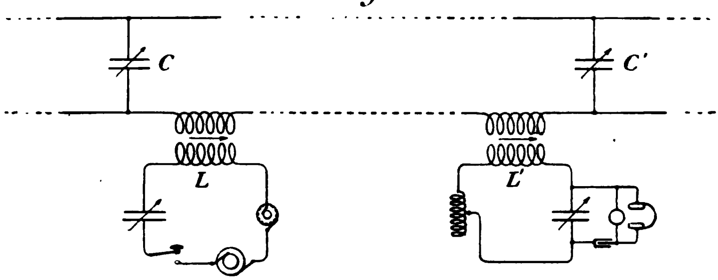


for wireless telephony, the coefficient of coupling being adjustable between wide limits. It was therefore a matter of hours to run through a large number of experiments in which various combinations were tried.

The transmitters first tried were those of the microphone type, inserted in the armature circuit of the dynamo and provided with water cooling when currents of several amperes were to be used.

It was soon found, however, that the efficiency of transmission of this cable line was so good for electric waves of these frequencies that a very small current, in the neighborhood of 2 milliamperes, sent into the line was amply sufficient for good speech at the receiving end, about 7 miles distant. No attempt was made to determine to what lower limit the transmission current could reach in this respect, but such small currents enabled the ordinary telephone transmitter to be used without any provision for cooling, especially when it was inserted in the line circuit instead of in the oscillatory circuit of the dynamo.

Fig. 7



The telephone receivers were those regularly furnished for wireless telephony, ranging in resistance from 2,000 to 8,000 ohms.

(b) SERIES ARRANGEMENT.

A circuit was next made up with high frequency apparatus inserted directly in the line in series instead of in the bridging arrangement shown in figure 5. The circuit used is shown diagrammatically in figure 7, in which L and L′ are the secondary coils of the transmitter and receiver, respectively. C and C′ represent variable condensers of the order of magnitude used in wireless telegraphy and serve as low impedence paths for the high-frequency oscillations, and at the same time prevent the short circuiting of the low-frequency battery telephone current. It was found that this arrangement gave apparently as good results as the bridging arrangement of the circuit.

RESONANCE.

As was expected, the phenomena of resonance under the conditions which here obtained were very pronounced and highly consistent, since we are here dealing with a definite circuit free from the disturbances and variations inherent in radio-telegraphy and telephony. In wireless telegraphy and telephony it is well known that within a few minutes transmission will drop off many fold from causes not entirely understood, and from diurnal variations and electrostatic disturbances effective transmission is often prevented.

In general, the different circuits were tuned to resonance in the same manner, for the same purpose, and with the same effect as in wireless telephony and telegraphy.

The line circuit itself was readily tuned to resonance for the particular frequency of the dynamo by noting the maximum reading of the hot wire ammeter A_1 in the line itself. This maximum is readily found by varying either the capacity C or the inductance L, or both.

At the receiving end of the line coil L′ and the condenser C′, as well as the coil L″ and the condenser C″, were tuned to give a maximum intensity of signals in the receiving telephone of the audion.

As stated above, the dynamo operated regularly at ranges from 100,000 cycles per second down to 20,000 cycles per second. It was therefore possible to try the effect of a comparatively wide range of frequencies in these experiments, covering three octaves, the inductances and capacities being chosen to correspond to each particular frequency. It was found that more energy was delivered over this particular type and length of circuit by using the lower frequencies of this range than the higher ones, although efficient results were easily obtained at any point.

The battery telephone side of the equipment was left absolutely intact, as it would be commercially used, and severe tests were made, employing four operators, to determine the efficiency of two simultaneous conversations over this same pair of wires.

The ringing circuit was operative both ways with no apparent effect on the high frequency telephone transmission. This ringing circuit develops a comparatively large alternating current flowing in the wire at about 30 cycles per second and at a voltage of many times that of either the high frequency or the battery side of the circuit.

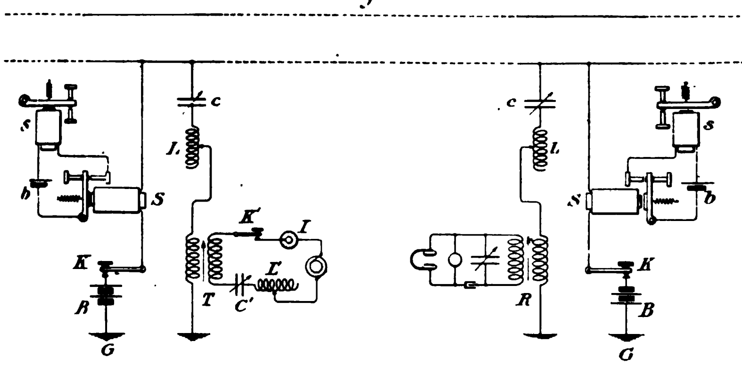
Articulation tests, including music, numerals, and other difficult combinations, gave satisfactory results, with no interference whatever between the two sides of the circuit.

By holding one telephone receiver to one ear and the other receiver to the other ear the receiving operator could hear two entirely different conversations simultaneously over the same pair of wires.

III. DUPLEX-DIPLEX TELEGRAPHY.

Having described in detail the experiments for obtaining the simultaneous transmission of two telephonic messages

Fig. 8.



over a single circuit, it will be apparent that the problem of transmitting two telegraphic messages over the same circuit may be solved by methods and apparatus, as far as the high-frequency side of the circuit is concerned, which are practically identical with those described above.

In this connection the metallic circuit referred to was equipped with a standard Morse set for manual operation, and upon this circuit was superimposed an equipment for transmitting in one direction telegraphic messages by means of sustained high-frequency oscillations, employing the telephone as the means for receiving the signals. The circuit used is shown diagrammatically in figure 8, in which, in the Morse set, there are shown between the line wire and the ground G, the line relay S, the key K, and the line battery B, and the local battery *b* and the sounder *s;* and in which, in the high-frequency set, are similarly shown between the line wire and the ground G the tuning elements C and L; and at the transmitting end the oscillation transformer T, the primary of which is in circuit with the dynamo as a source of sustained oscillations, the telegraph key K′, the interrupter 1 and the tuning elements C′ and L′, and at the receiving end the oscillation transformer R in the secondary circuit, of which are included the usual tuning elements and operatively connected to them the detector and its telephone as a means of receiving the signals.

As noted in the case of the preliminary local circuit tests, it was found that over this particular line it was not necessary to use a detector for electromagnetic waves, since enough energy was delivered to operate the telephone receiver directly without any tuning by connecting it between the line and the earth. The sound produced, however, was characteristically different in the two cases. With the detector the individual signals had the characteristic tone corresponding to the interrupter at the transmitting end of the line, whereas without the detector this tone was entirely absent, and a general dull sound, due to the resultant action of the wave trains, was heard. If, however, the telephone receiver employed a soft iron core, instead of a permanent magnet, no result was obtained with the limited power used on this line.

Although little mention of telegraphy by high-frequency electric waves has been made thus far, as a matter of fact it was found convenient during the experiments upon telephony actually to employ telegraphy as a quick and ready means of determining resonance between the circuits in each particular case.

When any particular arrangement was being employed the first steps were invariably to send simple Morse signals over the circuit until the operator at the distant end of the line reported maximum loudness in the receiving telephone, which indicated that the terminal apparatus with the line circuit was properly tuned. This being accomplished, it was only necessary to throw a switch, which substituted for the automatic interrupter and telegraph key the telephone transmitter. The experiments could then proceed on telephony without any material change being made at the receiving station. Telephony and telegraphy thus proceeded hand in hand as a mere matter of convenience, and one of the practical advantages in the use of electric waves for transmitting intelligence is that the whole set-up of apparatus is practically the same for each and they can be used interchangeably over the same circuit.

Considering the Morse equipment, indicated in figure 8, the electromagnetic units involved are of the order of magnitude of microfarads and henrys, and the period of the direct interrupted current for Morse sending is not more than the equivalent of about 10 complete cycles per second, whereas in the high-frequency side of the circuit we are dealing with electromagnetic units of the order of magnitude of thousandths of a microfarad and of thousandths of a henry and with frequencies not less than two thousand times greater than those involved in manual Morse sending. Furthermore, the ohmic resistance of the line, which plays a prominent part in limiting the distance and speed of Morse working, is comparatively unimportant in the case of electric waves guided by wires. The operation of the line equipped as in figure 8 was perfectly satisfactory, there being no perceptible interference between the two messages in either direction. Since the standard telegraph circuit of the world uses a ground-return circuit, this same equipment was arranged to operate on one of the wires of the twisted pair in the telephone cable as such a circuit with earth connections at each end.

Since it is a well-known essential of high-frequency apparatus used in tuned circuits that there shall be no iron involved in the circuit, it is evident that in cases where such a high-frequency circuit is to be superimposed upon a line comprising way stations, where line relays are inserted directly in the current, it will be necessary and sufficient to shunt such way stations by condensers of the order of magnitude of thousandths of a microfarad. Such condensers offer a comparatively free path for the high-frequency electric waves, but interpose a practical barrier to the Morse frequencies.

The same general statement can be made relative to any of the standard forms of low-frequency telegraphy over wires as now practiced, such as the polar duplex, the differential duplex, and the duplex-diplex, employing alternating currents of low frequency and standard keys, relays, and sounders.

Inserting a regular 150-ohm telegraph relay in series in the line cuts down the high-frequency current to a small percentage of its original value, which indicates the marked influence of the presence of iron in such a circuit. Furthermore, it was noted that at 100,000 cycles the hysteresis of the iron core at this period was so great that it became heated very perceptibly in a few moments.

Since a portion of the telegraph lines now used is still composed of iron wires, we should expect electric waves to be propagated over such wires less efficiently than over copper wires, since it is well known that electric waves penetrate only about one-thirteenth as deeply into soft iron for a given frequency as into copper, although this is modified by the fact that the iron in telegraph wires is not soft iron, and, in addition, is galvanized.

IV. MEASUREMENTS OF ELECTRIC WAVES OF FREQUENCIES FROM 20,000 TO 100,000 CYCLES PER SECOND ON A STANDARD TELEPHONE CABLE LINE.

In order to understand more fully the conditions for the successful transmission of electric waves along commercial telephone cable conductors, a preliminary study of this particular line has been made and the engineering data obtained is submitted.

In approaching the subject of these measurements, although the circuit involved is a wire circuit throughout, the method of treatment of the tests carried out has been that of wireless engineering rather than the usual tests made upon wire circuits. The range of frequencies used overlaps at its upper limit those which already have been employed in long distance wireless telegraphy, and at the lower limit approaches those used in telephone tests near the upper limit of audibility.

The measurements have been confined to the simple case of the metallic circuit, and other circuits involving ground connections have not been investigated.

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RESONANCE CURVES.

In order to determine in a general way the properties of this particular line independent of the receiving terminal apparatus, the first inquiry was directed to the construction of typical resonance curves in the cases, first, with the line open at the receiving end, and, second, with the line short-circuited at the receiving end, after which the modifications introduced by the presence of certain terminal apparatus were briefly investigated.

In order to indicate the general characteristics of these resonance curves as the frequency of the electric waves is varied, four particular frequencies were selected at approximately equal intervals from 95,000 complete cycles per second to 38,000 complete cycles per second, and at each of these frequencies two curves were obtained, one with the line open and the other with the line short-circuited at the receiving end.

The generator was operated either from a dynamo source or from a storage battery, and under proper conditions it ran so regularly and the whole phenomena of resonance were so regular and orderly that after a little practice the observations for each particular resonance curve could be taken as rapidly as the results could be recorded. Continuing the readings for a complete curve back and forth from beginning to end several times indicated that under proper conditions the readings agree so well that there was no necessity for averaging observations for any particular point, and a single set of observations for a curve was as accurate as desired.

It will be noted that in the observations given below the ammeter readings are equally spaced. This was convenient, since the variable tuning condenser could be easily adjusted to bring the ammeter needle to a division line on which it could be read more accurately than its position estimated in the uncalibrated space between. This removed any necessity for estimating divisions of the scale on the ammeter and contributed to accuracy.

The speed of the generator was determined by two methods, first, by observations with a tachometer upon a subsidiary shaft with a known ratio of rotation to that of the armature, and, second, by readings from a wave meter accurately calibrated by reference to the standards of inductance and capacity of the Bureau of Standards. The agreement between these was within the limits of error of observation.

COEFFICIENT OF COUPLING.

Since it was the desire to study the properties of the line itself, independent of any reactions from the local oscillatory circuit of the dynamo, loose coupling was invariably employed between these two circuits.

In taking the observations the coffiecient of coupling as defined by the expression

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

was made small by using a considerable separation between the primary and the secondary coils of the oscillation transformer, and there is no indication in the curves taken of reactive effects of the one circuit upon the other.

STIFFNESS FUNCTION, $\frac{L}{C}$.

Since resonance may be obtained in an oscillatory circuit by an infinite number of combinations of L and C fulfilling the condition

$$L\omega = \frac{1}{C\omega}$$

or more generally for series circuits containing series coils and condensers

$$\omega \Sigma L = \frac{1}{\omega} \Sigma \frac{1}{C},$$

it is possible to select any suitable value of either of these quantities and tune by varying the other. In making these observations the tuning inductance was kept constant and the capacity element varied.

The stiffness function $\frac{L}{C}$ was not kept constant for the different frequencies at which the resonance curves were taken, but its value for each set of observations is given.

A convenient range of variable inductances and capacities, calibrated in absolute values, was available, and the designs of these were such as are common in wireless telegraph practice, known as variometers and variable air condensers.

Hot-wire ammeters were placed in both the primary and the secondary circuits, the one in the primary being used merely to indicate the constancy of the speed of the dynamo, for which purpose this circuit was adjusted to the steepest part of its resonance curve, at which point the ammeter reading is very sensitive to change in speed.

The typical circuit for obtaining this series of resonance curves is shown diagrammatically in figure 9. The value of the primary current was controlled by the tuning inductance L′, the capacity C′ being constant.

RESONANCE CURVES AT $n = 93,800$, $\lambda = 3,200$ METERS.

(*a*) CASE 1: *Line open at receiving end.*—In Table I are given the observations for the resonance curves shown in figure 10.

TABLE I.—*Observations for resonance curves at transmitting end of telephone cable line, receiving end open.*

[Frequency of generator constant at 93,800 complete cycles per second.]

Capacity in microfarads in series with inductance at transmitting end.	Inductance in millihenrys in series with capacity at transmitting end.	Equivalent inductance of the line in millihenrys computed.	Wave length in meters.	Frequency of the line circuit.	Line current in milliamperes.
0.00183	0.400	....	2,070	145,000	50
.00210	.400	....	2,220	135,000	60
.00230	.400	....	2,320	129,000	70
.00248	.400	....	2,410	124,000	80
.00260	.400	....	2,470	121,000	90
.00266	.400	....	2,500	120,000	100
.00280	.400	....	2,570	117,000	110
.00288	.400	....	2,600	115,000	120
.00301	.400	....	2,660	113,000	130
.00312	.400	....	2,710	111,000	140
.00321	.400	....	2,750	109,000	150
.00329	.400	....	2,780	108,000	160
.00339	.400	....	2,820	106,000	170
.00351	.400	....	2,870	105,000	180
.00363	.400	....	2,920	103,000	190
.00373	.400	....	2,960	101,000	200
.00391	.400	....	3,030	99,000	210
.00436	.400	0.260	3,200	93,800	215
.00464	.400	....	3,300	90,900	200
.00511	.400	....	3,470	86,500	190
.00543	.400	....	3,570	84,000	180
.00571	.400	....	3,660	82,000	170
.00629	.400	....	3,850	77,900	160
.00668	.400	....	3,960	75,800	150
.00713	.400	....	4,100	73,200	140
.00768	.400	....	4,250	70,600	130
.00863	.400	....	4,500	66,700	120
.00914	.400	....	4,630	64,800	110
.01085	.400	....	5,050	59,400	100
.01335	.400	....	5,600	53,600	82

For tuning elements at resonance:

$$\frac{L}{C} = 0.917 \times 10^{5} \text{ for practical units.}$$

$$= 0.917 \times 10^{23} \text{ for absolute electromagnetic units.}$$

The inductance L was constant and equal to 0.400 millihenry, and the first column gives the values of the condenser C for the corresponding value of the line current in milliamperes, shown in the last column of the table.

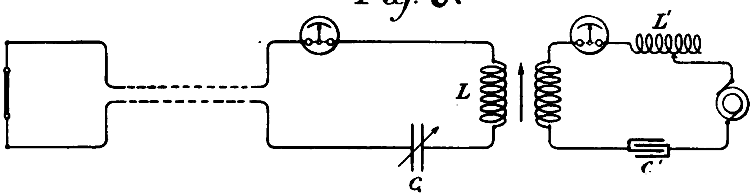
The construction of the curve is derived as follows:

For a simple series circuit at resonance we write

$$\lambda=\frac{v}{n}=2\pi v\sqrt{LC} \qquad (1)$$

in which λ is the wave length in centimeters, v is the velocity of light equals 3 by 10^{10} centimeters per second, n equals frequency in complete cycles per second; L is the sum of the inductances in the circuit in centimeters, and C is the total capacity in absolute electromagnetic units.

Fig. 9.



At resonance the value of n, and consequently the value of λ, is known, and is obtained from the frequency of the dynamo.

The value of the tuning condenser for the above condition of resonance is known, and from this we must first determine its capacity reactance at this frequency. From the table it is seen that for resonance the capacity was equal to 0.00436 microfarad and the capacity reactance of this condenser at a frequency of 93,800 is equal to

$$\frac{1}{C\omega}=389 \text{ ohms}$$

$$\text{or admittance}=2.57\times10^{-3} \text{ mho.}$$

From the table it is seen that the tuning inductance is equal to 0.400 millihenry, and its inductance reactance at this frequency is equal to

$$L\omega=236 \text{ mho}$$

$$\text{or admittance}=4.24\times10^{-3} \text{ mho.}$$

It appears, therefore, that of the tuning elements the reactance of the condenser is greater by 153 ohms than that of the coil, from which we may conclude that the line reac-

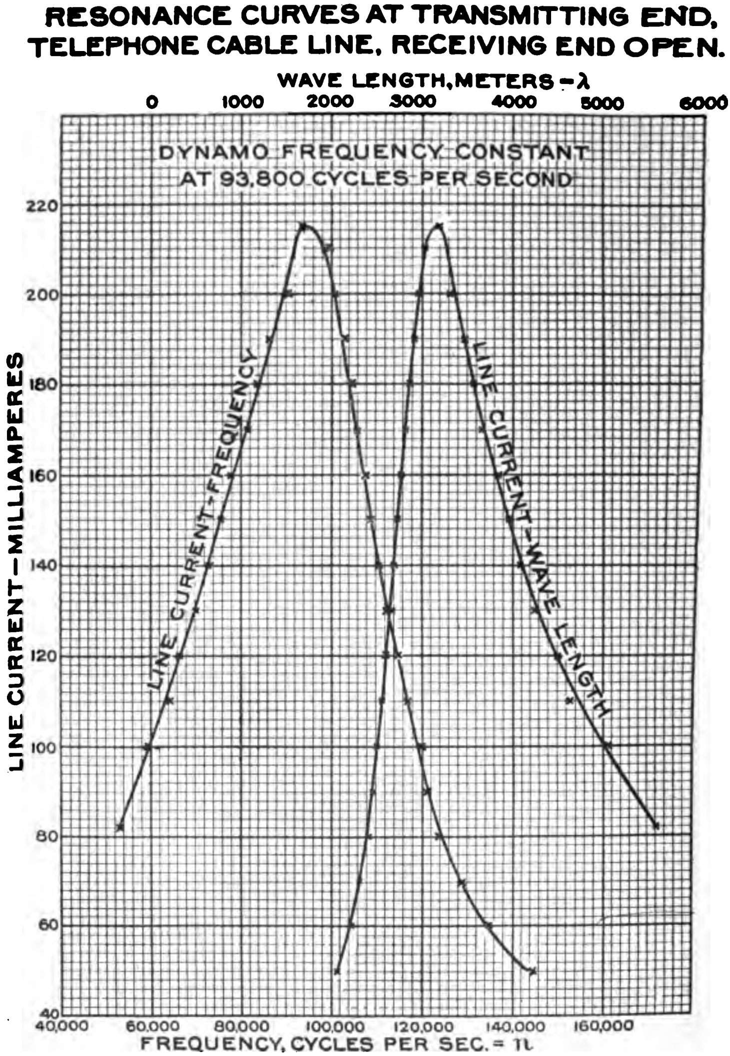


FIG. 10.

tance at this frequency is of the nature of an inductance instead of a capacity, since at resonance the geometric sum of the reactances of the circuit is zero.

We now have the necessary data to evaluate this equivalent inductance of the line at this frequency.

In equation (1) all the quantities are known except that part of L represented by the line, since the total inductance of the circuit is equal to the arithmetical sum of its parts, provided there is no mutual induction between any of these parts, which condition obtained in this case.

From equation (1) we write

$$\frac{v}{n} = 2\pi v \sqrt{(L + L^1)C} \qquad (2)$$

in which L^1 is the quantity to be determined. From which

$$L^1 = \frac{\frac{1}{n^2} - 4\pi^2 CL}{4\pi^2 C} \qquad (3)$$

$$= \frac{1}{4\pi^2 n^2 C} - L$$

Substituting the known values in (3) we have

$L^1 = 260{,}000$ centimeters.
$= .260$ millihenry.

It was desirable to measure the value of the effective voltage being impressed upon the line itself at the transmitting end, but no electrostatic voltmeter is available which will read directly small values for alternating electromotive forces.

The lowest reading of the electrostatic voltmeter available was 40, and this instrument when placed directly across the line gave no perceptible reading. It is possible, however, to estimate closely the voltage used, for since the ohmic resistance of the secondary coil in the line circuit was only a fraction of an ohm, the impedance of the coil at this frequency can be taken as practically 180° from that of the condenser without sensible error. The voltage drop across the coil at resonance is equal to

$$L\,\omega\,I = 236 \times 0.215 = 50.7 \text{ volts.}$$

The voltage drop across the condenser is equal to

$$\frac{I}{C\omega} = 389 \times 0.215 = 83.6 \text{ volts.}$$

Therefore, the voltage being impressed upon the line at resonance is

$$83.6 - 50.7 = 33 \text{ volts approximately.}$$

To determine other points of the resonance curve, we have these relations between the solution at resonance and any other solution at dissonance:

$$\lambda = \frac{v}{n} = 2\pi v\sqrt{LC}$$

$$\lambda_1 = \frac{v}{n_1} = 2\pi v\sqrt{L_1C_1}$$

$$\frac{n_1}{n} = \frac{\sqrt{LC}}{\sqrt{L_1C_1}}$$

$$n_1 = n\sqrt{\frac{LC}{L_1C_1}}$$

Since $L = L_1$ throughout a set of observations, we have

$$n_1 = n\sqrt{\frac{C}{C_1}} = \frac{k}{\sqrt{C_1}}$$

where $k = n\sqrt{C} =$ constant and C_1 is the observed value given in column one of Table 1.

Having determined in this manner the value of the frequencies for each of the points of dissonance given in the table, the corresponding wave-lengths in meters in the fourth column were derived.

The graphs of these curves are shown in figure 10.

It is observed that the line current-frequency curve is not symmetrical, but is steeper on the side of the higher frequencies.

The line current-wave length curve is steeper on the side of the shorter wave-length.

(*b*) CASE 2: *Line short-circuited at receiving end.*—With the dynamo frequency constant at 95,200 a similar set of observations was taken for the case of the receiving end of

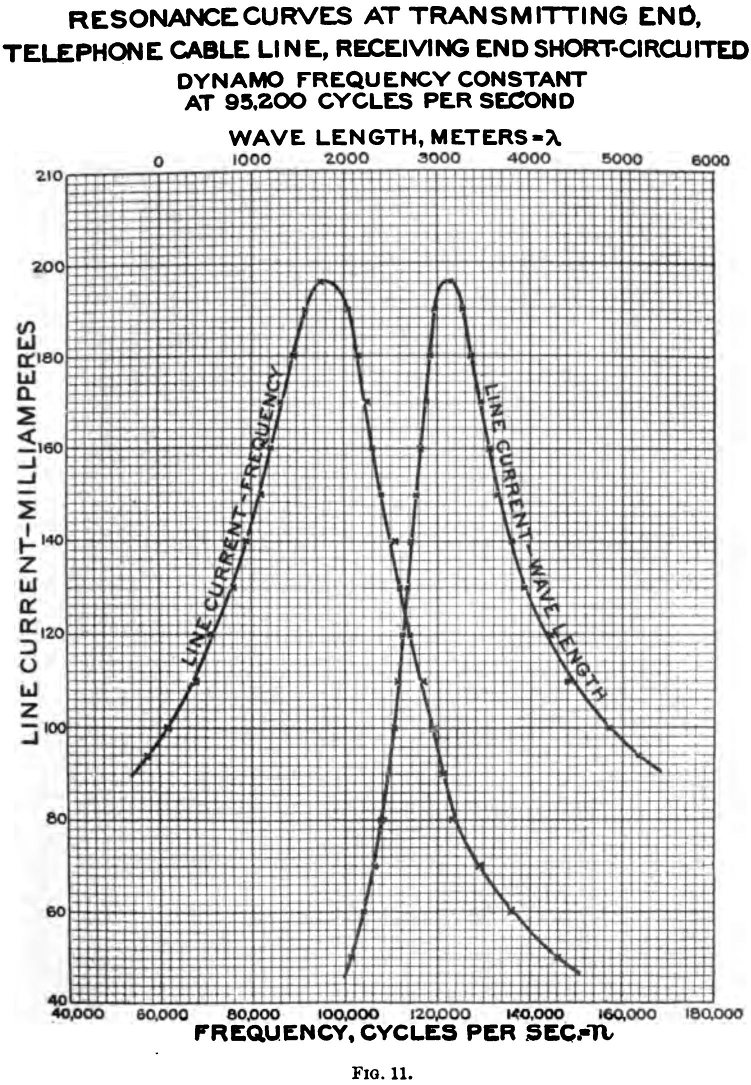


FIG. 11.

the line short-circuited, and these observations are exhibited in Table II.

The graphs for the line current-frequency and line current-wave length are shown in figure 11.

TABLE II.—*Observations for resonance curves at transmitting end of telephone cable line, receiving end short-circuited.*

[Frequency of generator constant at 95,200 complete cycles per second.]

Capacity in microfarads in series with inductance at transmitting end.	Inductance in millihenrys in series with capacity at transmitting end.	Equivalent inductance of the line in millihenrys computed.	Wave length in meters.	Frequency of the line circuit.	Line current in milliamperes.
0.00171	0.400	....	2,060	146,000	50
0.00195	0.400	....	2,200	136,000	60
0.00217	0.400	....	2,320	129,000	70
0.00238	0.400	....	2,430	123,000	80
0.00246	0.400	....	2,470	121,000	90
0.00258	0.400	....	2,530	119,000	100
0.00267	0.400	....	2,570	117,000	110
0.00279	0.400	....	2,630	114,000	120
0.00287	0.400	....	2,670	112,000	130
0.00297	0.400	....	2,710	111,000	140
0.00310	0.400	....	2,770	108,000	150
0.00322	0.400	....	2,830	106,000	160
0.00333	0.400	....	2,870	105,000	170
0.00342	0.400	....	2,910	103,000	180
0.00356	0.400	....	2,970	101,000	190
0.00400	0.400	0.295	3,150	95,200	196
0.00432	0.400	....	3,270	91,700	190
0.00457	0.400	....	3,370	89,000	180
0.00485	0.400	....	3,470	86,500	170
0.00510	0.400	....	3,560	84,300	160
0.00534	0.400	....	3,640	82,400	150
0.00581	0.400	....	3,800	78,900	140
0.00626	0.400	....	3,940	76,100	130
0.00718	0.400	....	4,220	71,100	120
0.00784	0.400	....	4,410	68,000	110
0.00950	0.400	....	4,850	61,900	100
0.01085	0.400	....	5,190	57,800	94

For tuning elements at resonance:

$$\frac{L}{C}=1.0\times10^{5} \text{ for practical units.}$$

$$=1.0\times10^{23} \text{ for absolute electromagnetic units.}$$

RESONANCE CURVES AT n=73,000. λ=4,110 METERS.

(a) CASE 1: *Line open at receiving end.*—In Table III are given the observations for the two curves shown in figure 12.

TABLE III.—*Observations for resonance curves at transmitting end of telephone cable line, receiving end open.*

[Frequency of generator constant at 73,000 complete cycles per second.]

Capacity in microfarads in series with inductance at transmitting end.	Inductance in millihenrys in series with capacity at transmitting end.	Equivalent inductance of the line in millihenrys computed.	Wave length in meters.	Frequency of the line circuit.	Line current in milliamperes.
0.00147	0.818	....	2,210	136,000	20
0.00208	0.818	....	2,630	114,000	30
0.00235	0.818	....	2,800	107,000	40
0.00268	0.818	....	2,990	100,000	50
0.00289	0.818	....	3,100	96,800	60
0.00309	0.818	....	3,210	93,500	70
0.00324	0.818	....	3,290	91,200	80
0.00343	0.818	....	3,380	88,800	90
0.00357	0.818	....	3,450	87,000	100
0.00367	0.818	....	3,500	85,700	110
0.00379	0.818	....	3,560	84,300	120
0.00387	0.818	....	3,590	83,600	130
0.00398	0.818	....	3,640	82,400	140
0.00407	0.818	....	3,680	81,500	150
0.00416	0.818	....	3,730	80,400	160
0.00423	0.818	....	3,760	79,800	170
0.00435	0.818	....	3,810	78,700	180
0.00444	0.818	....	3,850	77,900	190
0.00455	0.818	....	3,890	77,100	200
0.00464	0.818	....	3,930	76,300	210
0.00478	0.818	....	3,990	75,200	220
0.00506	0.818	0.121	4,110	73,000	227
0.00527	0.818	....	4,190	71,600	220
0.00547	0.818	....	4,270	70,300	210
0.00563	0.818	....	4,330	69,300	200
0.00577	0.818	....	4,390	68,300	190
0.00594	0.818	....	4,450	67,400	180
0.00611	0.818	....	4,510	66,500	170
0.00629	0.818	....	4,580	65,500	160
0.00651	0.818	....	4,660	64,400	150
0.00675	0.818	....	4,740	63,300	140
0.00707	0.818	....	4,850	61,900	130
0.00741	0.818	....	4,970	60,400	120
0.00789	0.818	....	5,130	58,500	110
0.00858	0.818	....	5,350	56,100	100
0.00950	0.818	....	5,630	53,300	90
0.01105	0.818	....	6,070	49,400	80
0.01346	0.818	....	6,700	44,800	70
0.01905	0.818	....	7,970	37,600	60

For tuning elements at resonance:

$\frac{L}{C}=1.62\times10^{5}$ for practical units.

$=1.62\times10^{23}$ for absolute electromagnetic units.

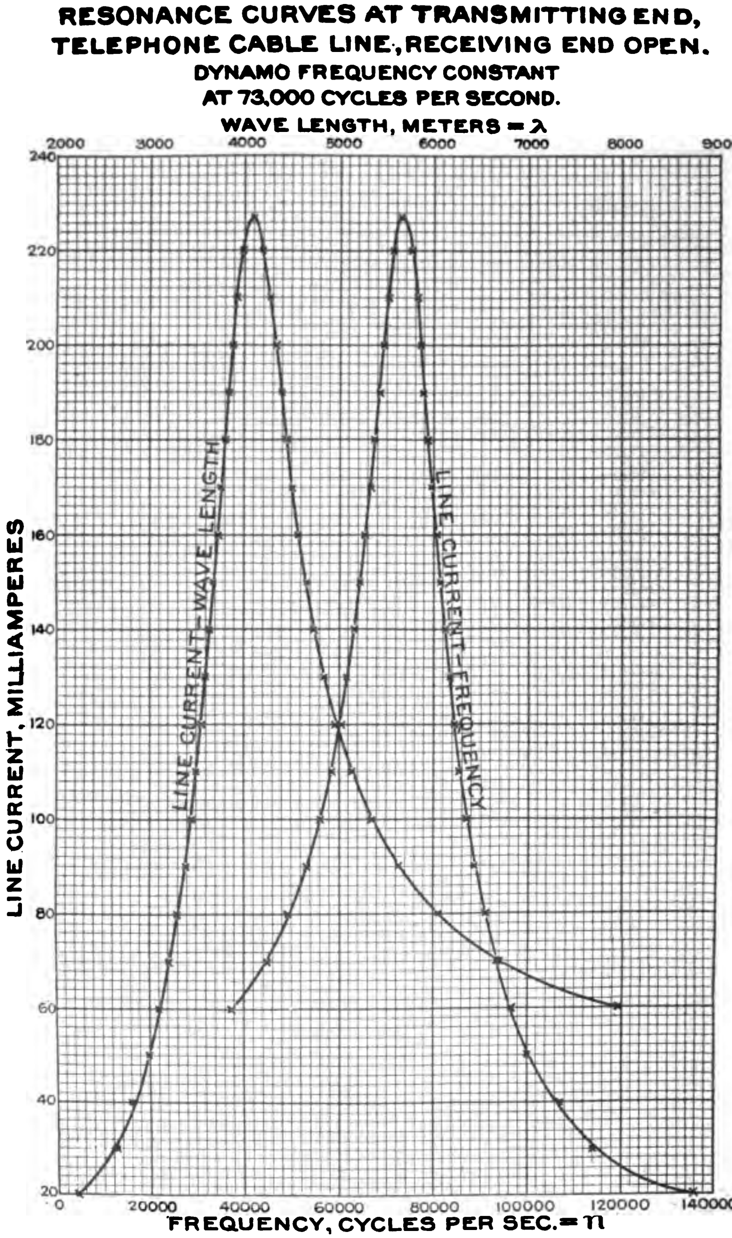

RESONANCE CURVES AT TRANSMITTING END,
TELEPHONE CABLE LINE, RECEIVING END OPEN.
DYNAMO FREQUENCY CONSTANT
AT 73,000 CYCLES PER SECOND.
WAVE LENGTH, METERS = λ
2000
3000
4000
5000
6000
7000
8000
9000
240
220
200
180
160
140
120
100
80
60
40
20
LINE CURRENT, MILLIAMPERES
LINE CURRENT-WAVE LENGTH
LINE CURRENT-FREQUENCY
0
20000
40000
60000
80000
100000
120000
140000
FREQUENCY, CYCLES PER SEC. = n

FIG. 12.

(*b*) CASE A: *Line short-circuited at receiving end.*—In Table IV are given the observations for the two resonance curves shown in figure 13.

TABLE IV.—*Observations for resonance curves at transmitting end of telephone cable line, receiving end short-circuited.*

[Frequency of generator constant at 73,000 complete cycles per second.]

Capacity in microfarads in series with inductance at transmitting end.	Inductance in millihenrys in series with capacity at transmitting end.	Equivalent inductance of the line in millihenrys computed.	Wave length in meters.	Frequency of the line circuit.	Line current in milliamperes.
0.00144	0.818	...	2,230	134,000	20
0.00197	0.818	...	2,600	115,000	30
0.00227	0.818	...	2,790	108,000	40
0.00253	0.818	...	2,950	102,000	50
0.00281	0.818	...	3,110	96,500	60
0.00298	0.818	...	3,200	93,800	70
0.00315	0.818	...	3,290	91,200	80
0.00332	0.818	...	3,380	88,800	90
0.00345	0.818	...	3,450	87,000	100
0.00358	0.818	...	3,510	85,500	110
0.00369	0.818	...	3,560	84,300	120
0.00376	0.818	...	3,600	83,300	130
0.00387	0.818	...	3,650	82,200	140
0.00396	0.818	...	3,690	81,300	150
0.00404	0.818	...	3,730	80,400	160
0.00415	0.818	...	3,780	79,400	170
0.00425	0.818	...	3,820	78,500	180
0.00430	0.818	...	3,850	77,900	190
0.00439	0.818	...	3,890	77,100	200
0.00452	0.818	...	3,940	76,100	210
0.00464	0.818	...	4,000	75,000	220
0.00491	0.818	0.150	4,110	73,000	227
0.00515	0.818	...	4,210	71,300	220
0.00533	0.818	...	4,280	70,100	210
0.00551	0.818	...	4,350	69,000	200
0.00566	0.818	...	4,410	68,000	190
0.00585	0.818	...	4,490	66,800	180
0.00600	0.818	...	4,540	66,100	170
0.00620	0.818	...	4,620	64,900	160
0.00640	0.818	...	4,690	64,000	150
0.00666	0.818	...	4,790	62,600	140
0.00697	0.818	...	4,900	61,200	130
0.00731	0.818	...	5,020	59,800	120
0.00775	0.818	...	5,160	58,100	110
0.00848	0.818	...	5,400	55,600	100
0.00940	0.818	...	5,690	52,700	90
0.01087	0.818	...	6,120	49,000	80
0.01332	0.818	...	6,770	44,300	70
0.01905	0.818	...	8,100	37,000	60

For tuning elements at resonance:

$$\frac{L}{C} = 1.67 \times 10^{5} \text{ for practical units.}$$

$$= 1.67 \times 10^{23} \text{ for absolute electromagnetic units.}$$

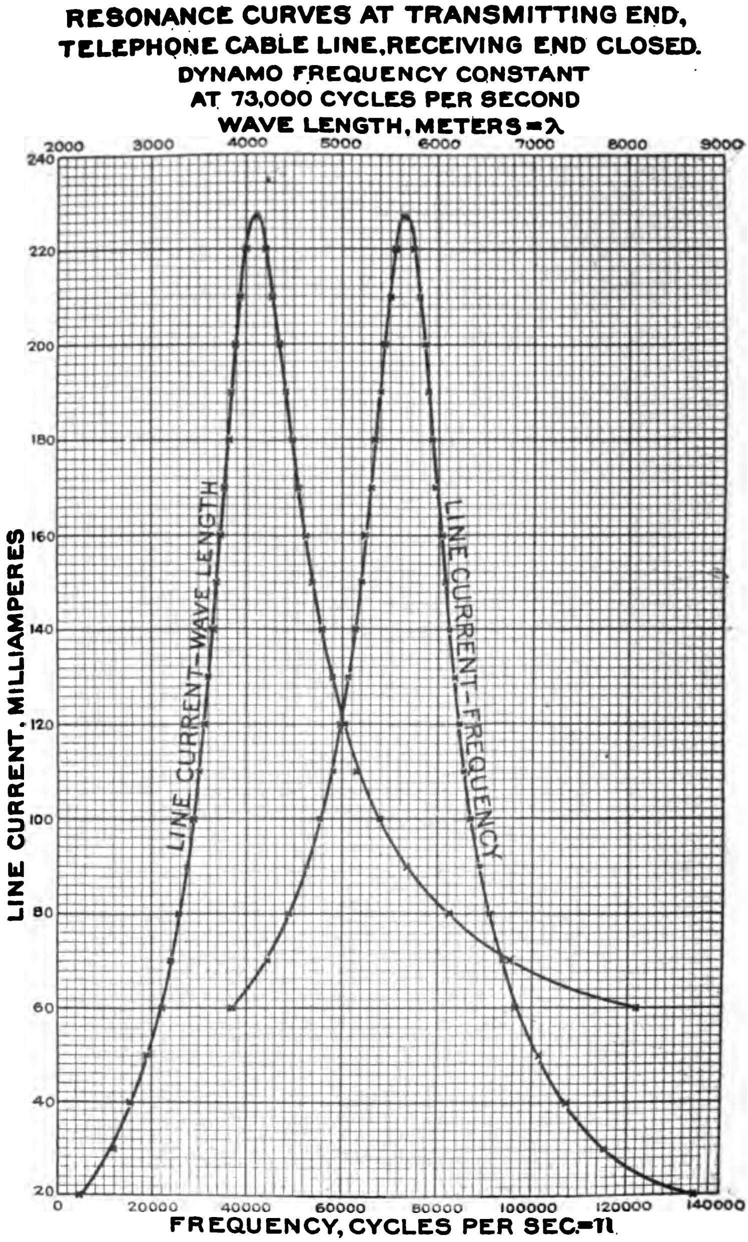

RESONANCE CURVES AT TRANSMITTING END,
TELEPHONE CABLE LINE, RECEIVING END CLOSED.
DYNAMO FREQUENCY CONSTANT
AT 73,000 CYCLES PER SECOND
WAVE LENGTH, METERS = λ
2000
3000
4000
5000
6000
7000
8000
9000
240
220
200
180
160
140
120
100
80
60
40
20
LINE CURRENT, MILLIAMPERES
LINE CURRENT-WAVE LENGTH
LINE CURRENT-FREQUENCY
0
20000
40000
60000
80000
100000
120000
140000
FREQUENCY, CYCLES PER SEC. = n

FIG. 13.

RESONANCE CURVES AT $n=53{,}000$, $\lambda=5{,}660$ METERS.

(*a*) Case 1: *Line open at receiving end.*—In Table V are given the observations for the two curves shown in figure 14.

Table V.—*Observations for resonance curves at transmitting end of telephone cable line, receiving end open.*

[Frequency of generator constant at 53,000 complete cycles per second.]

Capacity in microfarads in series with inductance at transmitting end.	Inductance in millihenrys in series with capacity at transmitting end.	Equivalent capacity of the line in microfarads computed.	Wave length in meters.	Frequency of the line circuit.	Line current in milliamperes.
0.00452	1.036	....	4040	74,300	50
0.00494	1.036	....	4220	71,100	60
0.00542	1.036	....	4420	67,900	70
0.00570	1.036	....	4530	66,200	80
0.00600	1.036	....	4640	64,700	90
0.00624	1.036	....	4730	63,400	100
0.00672	1.036	....	4910	61,100	110
0.00700	1.036	....	5000	60,000	120
0.00723	1.036	....	5080	59,100	130
0.00747	1.036	....	5160	58,100	140
0.00777	1.036	....	5260	57,000	150
0.00816	1.036	....	5390	55,700	160
0.00902	1.036	0.251	5660	53,000	170
0.00988	1.036	....	5910	50,800	160
0.01036	1.036	....	6050	49,600	150
0.01086	1.036	....	6190	48,500	140
0.01175	1.036	....	6260	47,900	130
0.01172	1.036	....	6420	46,700	120
0.01232	1.036	....	6570	45,700	110
0.01355	1.036	....	6880	43,600	100
0.01522	1.036	....	7260	41,300	90
0.01860	1.036	....	7980	37,600	80

For tuning elements at resonance:

$\frac{L}{C}=1.15\times10^{5}$ for practical units.

$=1.15\times10^{23}$ for absolute electromagnetic units.

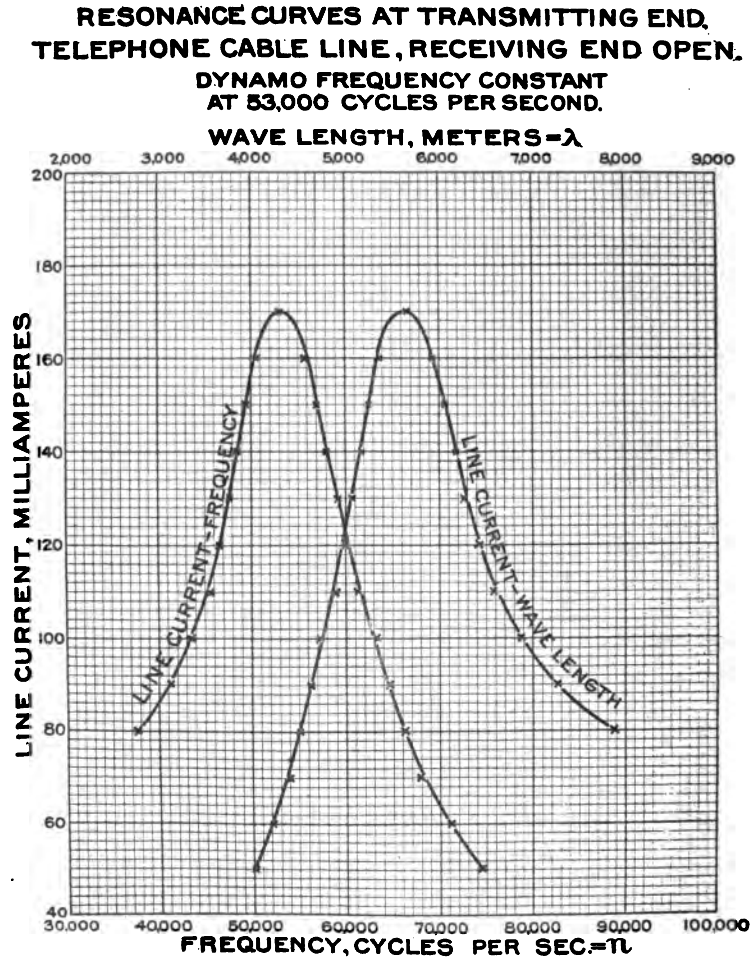

RESONANCE CURVES AT TRANSMITTING END.
TELEPHONE CABLE LINE, RECEIVING END OPEN.
DYNAMO FREQUENCY CONSTANT
AT 53,000 CYCLES PER SECOND.
WAVE LENGTH, METERS=λ
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
200
180
160
140
120
100
80
60
40
LINE CURRENT, MILLIAMPERES
LINE CURRENT-FREQUENCY
LINE CURRENT-WAVE LENGTH
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
FREQUENCY, CYCLES PER SEC.=n

FIG. 14.

(*b*) CASE 2: *Line short-circuited at receiving end.*—In Table VI are given the observations for the two resonance curves shown in figure 15.

TABLE VI.—*Observations for resonance curves at transmitting end of telephone cable line, receiving end short-circuited.*

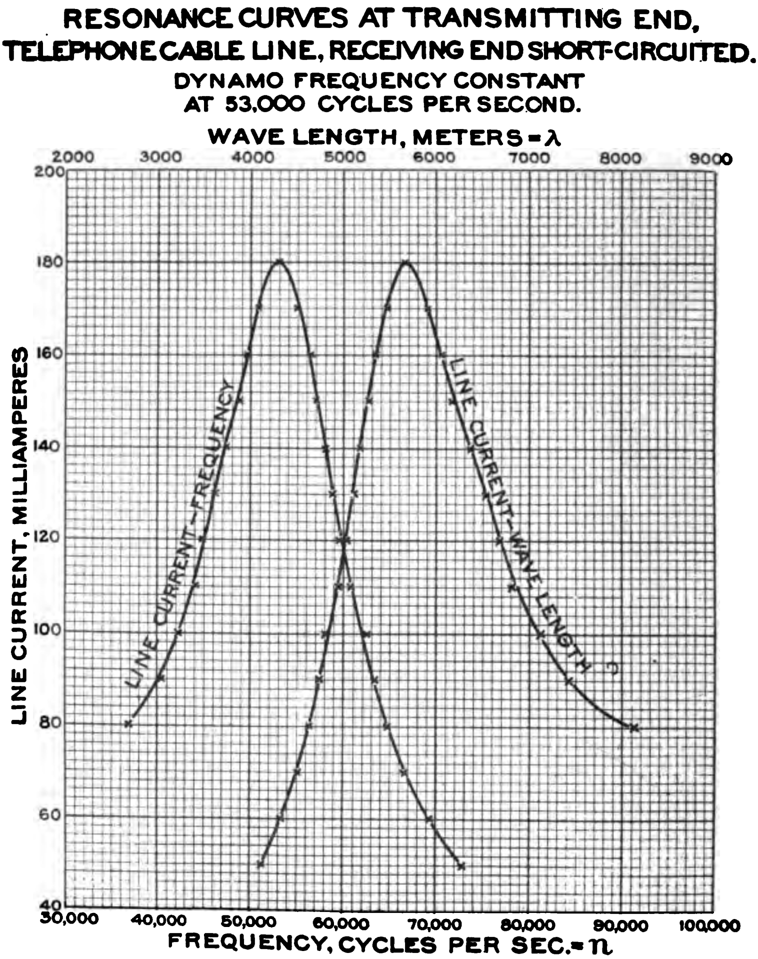
[Frequency of generator constant at 53,000 complete cycles per second.]

Capacity in microfarads in series with inductance at transmitting end.	Inductance in millihenrys in series with capacity at transmitting end.	Equivalent capacity of the line in microfarads computed.	Wave length in meters	Frequency of the line circuit.	Line current in milliamperes.
0.00469	1.036	....	4,120	72,800	50
0.00516	1.036	....	4,320	69,400	60
0.00564	1.036	....	4,510	66,500	70
0.00598	1.036	....	4,640	64,700	80
0.00624	1.036	....	4,740	63,300	90
0.00642	1.036	....	4,800	62,500	100
0.00682	1.036	....	4,950	60,600	110
0.00708	1.036	....	5,040	59,500	120
0.00729	1.036	....	5,110	58,700	130
0.00749	1.036	....	5,180	57,900	140
0.00777	1.036	....	5,270	56,900	150
0.00796	1.036	....	5,330	56,300	160
0.00838	1.036	....	5,470	54,800	170
0.00900	1.036	0.265	5,660	53,000	180
0.00981	1.036	....	5,900	50,800	170
0.01030	1.036	....	6,040	49,700	160
0.01068	1.036	....	6,150	48,800	150
0.01138	1.036	....	6,340	47,300	140
0.01202	1.036	....	6,510	46,100	130
0.01269	1.036	....	6,680	44,900	120
0.01318	1.036	....	6,800	44,100	110
0.01450	1.036	....	7,110	42,200	100
0.01587	1.036	....	7,420	40,400	90
0.01932	1.036	....	8,140	36,900	80

For tuning elements at resonance:

$$\frac{L}{C} = 1.15 \times 10^{23} \text{ for practical units.}$$

$$= 1.15 \times 10^{23} \text{ for absolute electromagnetic units.}$$



RESONANCE CURVES AT TRANSMITTING END,
TELEPHONE CABLE LINE, RECEIVING END SHORT-CIRCUITED.
DYNAMO FREQUENCY CONSTANT
AT 53,000 CYCLES PER SECOND.
WAVE LENGTH, METERS = λ
2000
3000
4000
5000
6000
7000
8000
9000
200
180
160
140
120
100
80
60
40
LINE CURRENT, MILLIAMPERES
LINE CURRENT—FREQUENCY
LINE CURRENT—WAVE LENGTH
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
FREQUENCY, CYCLES PER SEC. = n

FIG. 15.

RESONANCE CURVES AT $n=38,500$ $\lambda=7,790$ METERS.

(*a*) CASE 1: *Line open at receiving end.*—In Table VII are given the observations for the two curves shown in figure 16.

TABLE VII.—*Observations for resonance curves at transmitting end of telephone cable line, receiving end open.*

[Frequency of generator constant at 38,500 complete cycles per second.]

Capacity in microfarads in series with inductance at transmitting end.	Inductance in millihenrys in series with capacity at transmitting end.	Equivalent inductance of the line in millihenrys computed.	Wave length in meters.	Frequency of the line circuit.	Line current in milliamperes.
0.00215	0.818	....	3,540	84,700	20.0
0.00298	0.818	....	4,160	72,100	30.0
0.00347	0.818	....	4,490	66,800	40.0
0.00407	0.818	....	4,860	61,700	50.0
0.00450	0.818	....	5,120	58,600	60.0
0.00495	0.818	....	5,360	56,000	70.0
0.00525	0.818	....	5,520	54,300	80.0
0.00551	0.818	....	5,660	53,000	90.0
0.00589	0.818	....	5,850	51,300	100.0
0.00600	0.818	....	5,900	50,800	110.0
0.00631	0.818	....	6,060	49,500	120.0
0.00655	0.818	....	6,170	48,600	130.0
0.00681	0.818	....	6,290	47,700	140.0
0.00700	0.818	....	6,380	47,000	150.0
0.00730	0.818	....	6,520	46,000	160.0
0.00756	0.818	....	6,630	45,200	170.0
0.00780	0.818	....	6,740	44,500	180.0
0.00809	0.818	....	6,860	43,700	190.0
0.00834	0.818	....	6,960	43,100	200.0
0.00877	0.818	....	7,140	42,000	210.0
0.00894	0.818	....	7,210	41,600	220.0
0.00923	0.818	....	7,320	41,000	230.0
0.01015	0.818	....	7,680	39,100	240.0
0.01044	0.818	0.818	7,790	38,500	241.5
0.01076	0.818	....	7,910	37,900	240.0
0.01170	0.818	....	8,250	36,400	230.0
0.01220	0.818	....	8,420	35,600	220.0
0.01268	0.818	....	8,590	34,900	210.0
0.01332	0.818	....	8,800	34,100	200.0
0.01397	0.818	....	9,020	33,300	190.0
0.01484	0.818	....	9,290	32,300	180.0
0.01554	0.818	....	9,500	31,600	170.0
0.01687	0.818	....	9,910	30,300	160.0
0.01844	0.818	....	10,400	28,800	150.0
0.02005	0.818	....	10,800	27,800	140.0
0.02247	0.818	....	11,400	26,300	130.0
0.02541	0.818	....	12,200	24,600	120.0
0.03091	0.818	....	13,400	22,400	110.0
0.03978	0.818	....	15,200	19,700	101.5

For tuning elements at resonance:

$$\frac{L}{C} = 0.784 \times 10^{5} \text{ for practical units.}$$
$$= 0.784 \times 10^{23} \text{ for absolute electromagnetic units.}$$

RESONANCE CURVES AT TRANSMITTING END, TELEPHONE CABLE LINE, RECEIVING END OPEN.
DYNAMO FREQUENCY CONSTANT AT 38.500 CYCLES PER SECOND.

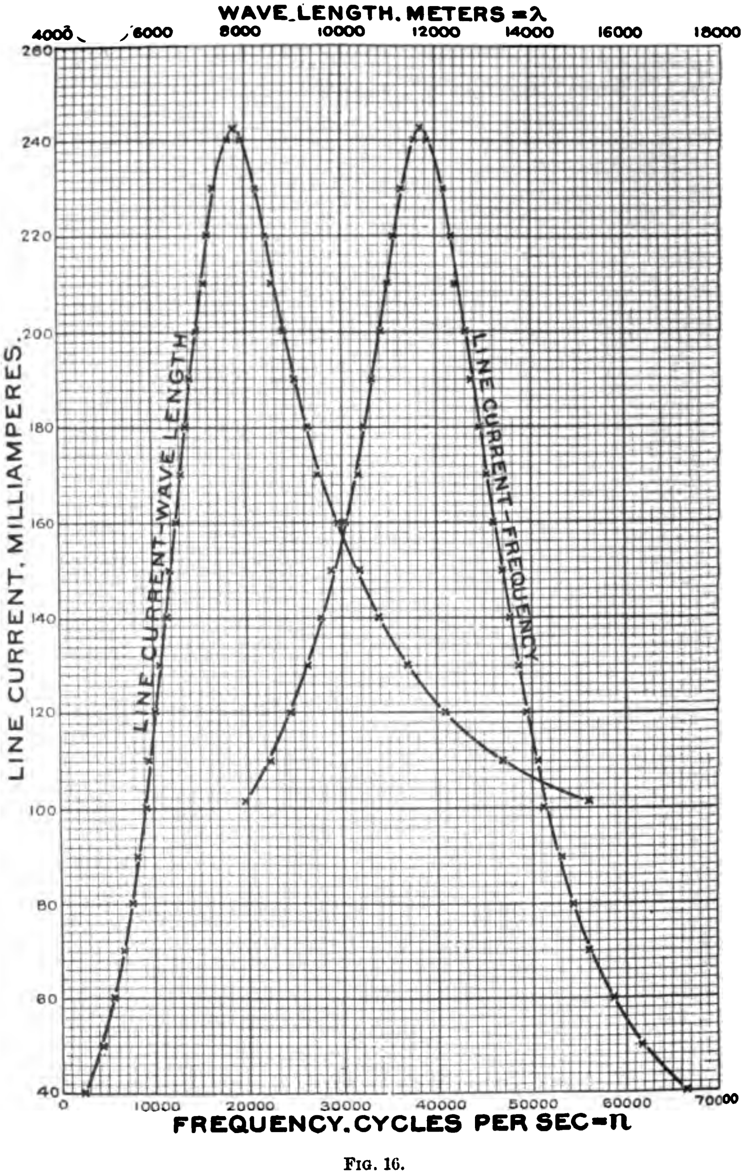


Fig. 16.

(*b*) CASE 2. *Line short-circuited at receiving end.*—In Table VIII are given the observations for the two resonance curves shown in figure 17.

TABLE VIII.—*Observations for resonance curves at transmitting end of telephone cable line, receiving end short-circuited.*

[Frequency of generator constant at 38,000 complete cycles per second.]

Capacity in microfarads in series with inductance at transmitting end.	Inductance in millihenrys in series with capacity at transmitting end.	Equivalent inductance of the line in millihenrys computed.	Wave length in meters.	Frequency of the line circuit.	Line current in milliamperes.
0.00217	0.818	....	3,990	75,200	20
0.00291	0.818	....	4,620	64,900	30
0.00337	0.818	....	4,970	60,400	40
0.00384	0.818	....	5,300	56,600	50
0.00428	0.818	....	5,600	53,600	60
0.00507	0.818	....	6,090	49,300	70
0.00491	0.818	....	5,990	50,100	80
0.00516	0.818	....	6,150	48,800	90
0.00539	0.818	....	6,280	47,800	100
0.00559	0.818	....	6,400	46,900	110
0.00581	0.818	....	6,520	46,000	120
0.00597	0.818	....	6,610	45,400	130
0.00601	0.818	....	6,630	45,200	140
0.00630	0.818	....	6,790	44,200	150
0.00649	0.818	....	6,890	43,500	160
0.00661	0.818	....	6,960	43,100	170
0.00679	0.818	....	7,050	42,600	180
0.00694	0.818	....	7,130	42,100	190
0.00714	0.818	....	7,230	41,500	200
0.00733	0.818	....	7,320	41,000	210
0.00758	0.818	....	7,450	40,300	220
0.00850	0.818	1.26	7,890	38,000	230
0.00894	0.818	....	8,090	37,100	220
0.00935	0.818	....	8,270	36,300	210
0.00961	0.818	....	8,380	35,800	200
0.00995	0.818	....	8,540	35,100	190
0.01031	0.818	....	8,690	34,500	180
0.01070	0.818	....	8,850	33,900	170
0.01101	0.818	....	8,980	33,400	160
0.01175	0.818	....	9,280	32,300	150
0.01234	0.818	....	9,500	31,600	140
0.01318	0.818	....	9,820	30,500	130
0.01412	0.818	....	10,200	29,400	120
0.01537	0.818	....	10.600	28,300	110
0.01737	0.818	....	11,300	26,500	100
0.02033	0.818	....	12,200	24,600	90
0.02530	0.818	....	13,600	22,000	80
0.03978	0.818	....	17,100	17,500	70

For tuning elements at resonance:

$\frac{L}{C} = .963 \times 10^{5}$ for practical units.

$= .963 \times 10^{23}$ for absolute electromagnetic units.

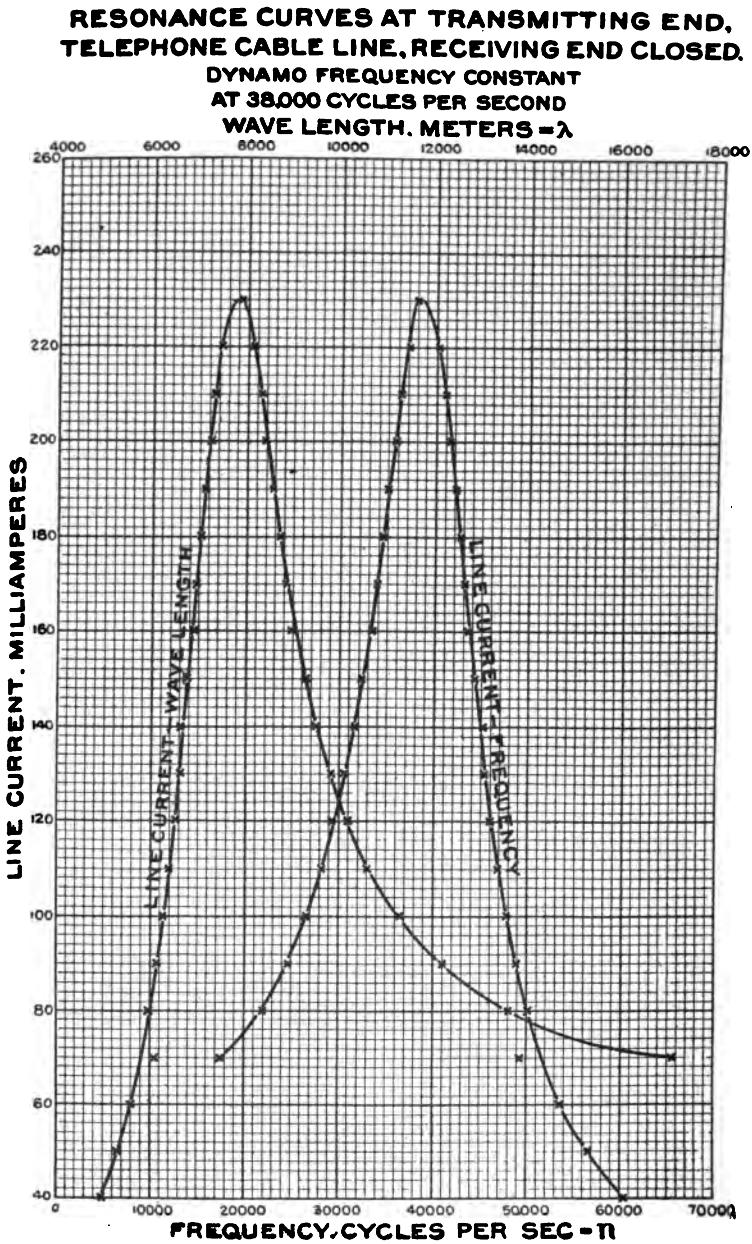

RESONANCE CURVES AT TRANSMITTING END,
TELEPHONE CABLE LINE, RECEIVING END CLOSED.
DYNAMO FREQUENCY CONSTANT
AT 38,000 CYCLES PER SECOND
WAVE LENGTH. METERS = λ
4000
6000
8000
10000
12000
14000
16000
18000
260
240
220
200
180
160
140
120
100
80
60
40
LINE CURRENT. MILLIAMPERES
LINE CURRENT—WAVE LENGTH
LINE CURRENT—FREQUENCY
0
10000
20000
30000
40000
50000
60000
70000
FREQUENCY, CYCLES PER SEC = n

FIG. 17.

SELECTIVITY CURVES.

The series of resonance curves given above are the usual types constructed in the study of wireless antennæ, but in order to interpret them from an engineering point of view it is more valuable to plot them as selectivity curves, in which the line current is plotted as a function of the frequency.

In order to be able to read directly the percentage drop in current from the value at resonance taken as unity, for any given percentage departure from the frequency at resonance also taken as unity, we have only to plot ordinates in terms of $\frac{I}{I_r}$, in which I is any particular value of the current corresponding to the frequency n_1, and I_r is the value of the current at resonance; and abscissæ in terms of $\frac{n_1}{n}$, in which n_1 is the frequency of the line circuit at any point of dissonance, and n is the frequency at resonance.

As an example, in the case of n equals 53,000, Table IX has been computed. The graph of this curve is shown in figure 18.

TABLE IX.—*Data for selectivity curve of telephone cable line, receiving end short-circuited.*

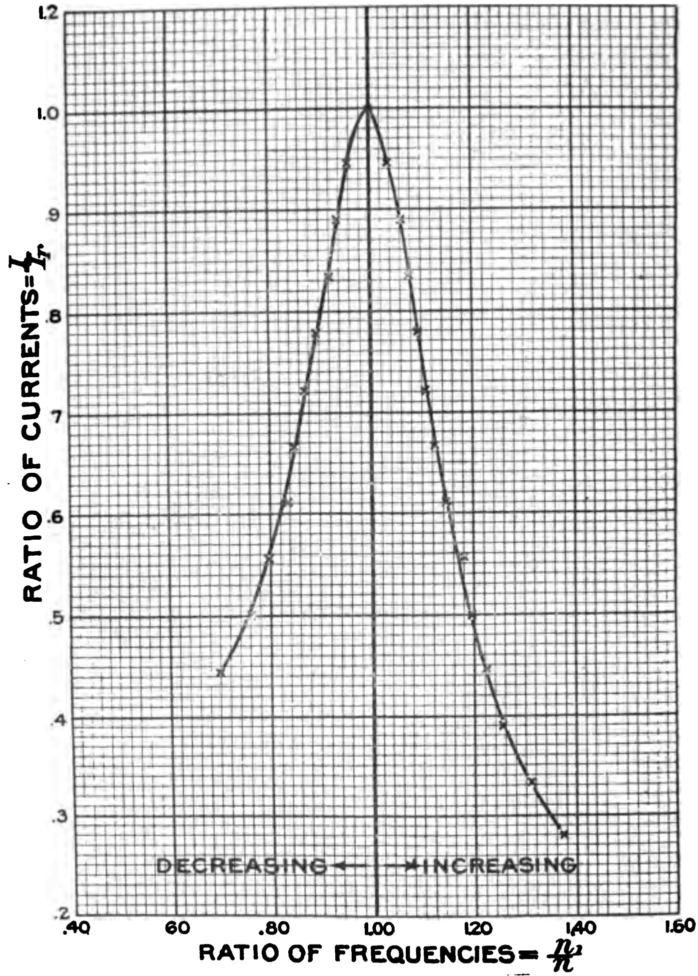
[Frequency of generator constant at 53,000 complete cycles per second.]

n_1	I	$\frac{n_1}{n}$	$\frac{I}{I_r}$
72,800	50	1.374	0.278
69,400	60	1.310	0.333
66,500	70	1.255	0.388
64,700	80	1.221	0.444
63,300	90	1.194	0.500
62,500	100	1.180	0.556
60,600	110	1.144	0.611
59,500	120	1.123	0.667
58,700	130	1.108	0.722
57,900	140	1.092	0.778
56,900	150	1.074	0.833
56,300	160	1.062	0.889
54,800	170	1.034	0.945
53,000	180	1.000	1.000
50,800	170	0.958	0.945
49,700	160	0.938	0.889
48,800	150	0.921	0.833
47,300	140	0.892	0.778
46,100	130	0.870	0.722
44,900	120	0.847	0.667
44,100	110	0.832	0.611
42,200	100	0.796	0.556
40,400	90	0.762	0.500
36,900	80	0.698	0.444

n_1 Frequency of line circuit tuned to given dissonance with generator frequency.
I Measured line current at frequency n_1, in milliamperes.
n Impressed frequency of generator, constant at 53,000 cycles per second.
I_r Maximum current in line circuit, tuned to resonance with generator frequency, 180 milliamperes.

SELECTIVITY CURVE OF TELEPHONE CABLE LINE. RECEIVING END SHORT-CIRCUITED.

IMPRESSED FREQUENCY CONSTANT AT 53,000 CYCLES PER SEC.



I_r = Line current at resonance
I = Line current
n = Frequency at resonance
n_1 = Frequency of Line Circuit tuned to given dissonance.

FIG. 18.

It appears from the inspection of this curve that it is not symmetrical with respect to the ordinate corresponding to resonance. The slope of the curve is steeper for increasing frequencies than for decreasing frequencies. We are enabled to read off directly from this curve the percentage change in the line current from resonance for any given percentage change in frequency from resonance. For instance, it is seen that for 10 per cent decrease in the frequency of the line circuit, the current has fallen to 79 per cent of its value at resonance, and at 30 per cent decrease in frequency of the line circuit the current has fallen to 44 per cent of its value at resonance, whereas at 30 per cent increase in frequency of the line circuit the current has fallen to 34 per cent of its value at resonance, which is considerably lower; in other words, the line current is more sensitive to changes on the side of increasing frequencies than on the side of decreasing frequencies in the case of impressed constant frequency of the dynamo of 53,000 cycles per second.

The current is seen to be reduced to one-half its value at resonance for a 24 per cent reduction in frequency, and to the same amount for 20 per cent increase of frequency.

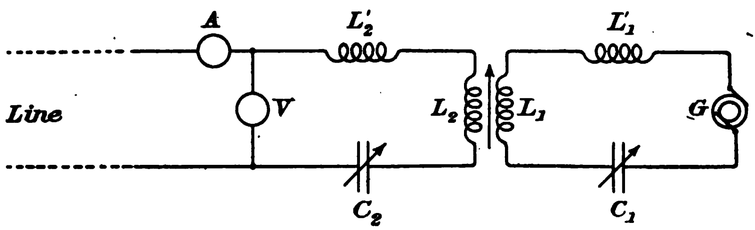
A curve of this kind enables us to predict that terminal apparatus could be inserted in this line at the receiving end, provided it was in the nature of ohmic resistance, and that there would be no interference between several of such instruments operated at different frequencies, provided the interval between the frequencies of each of the different receiving sets was greater than 44 per cent, and that each receiving apparatus was not rendered inoperative by the presence of a stray current of 50 per cent of its normal operating value. It should be remembered that this interpretation is from conditions controllable at the transmitting end only, and provides for no selective tuning whatever of the apparatus at the receiving end. In other words, the curve given shows the selectivity of the line itself.

ELECTRICAL DIMENSIONS OF TUNING ELEMENTS.

For the range of frequencies involved in these experiments the standard variable air condensers and variometers which are at present employed in wireless telegraph practice, could better be made of larger electrical dimensions in order to be better adapted to the frequencies here considered.

It is noted from the tables submitted that capacities as large as hundredths of a microfarad were at times used, and in order to secure these it was necessary to join several of the air condensers of wireless telegraph pattern in parallel, adding their results. In like manner the inductances used were as high as 3 millihenrys in some cases. Fortunately, capacities and inductances can be easily constructed which at the same time preserve the continuously variable feature necessary for tuning purposes, and may have also compact physical dimensions; in fact, in suitable designs for these frequencies these tuning elements may be even smaller and more compact than they now are for wireless telegraph practice. This is for the reason that in the case of electric waves impressed upon wires we are not dealing with high voltages such as are required in apparatus using an antenna. Furthermore, by properly designing inductances in accord-

Fig. 19.



ance with the fundamental formulæ laid down by Maxwell, it is evident that variometers suitable for this range of frequencies impressed upon wire circuits may be made extremely small and compact.

It should be noted that throughout these experiments not a single piece of new apparatus was designed or constructed, but the conventional apparatus as now employed in wireless telegraph engineering was adopted as a whole, although, as stated above, this apparatus could be very materially improved in the line of compactness of design for this range of frequencies.

Since no cases of high voltage were required at the transmitting end of the line, the same form of apparatus was used interchangeably for transmitting and receiving, whereas in wireless practice the transmitting antenna coils and condensers are very large in comparison with those used for receiving.

IMPEDANCE-FREQUENCY CURVE AT RESONANCE, TRANSMITTING END OF TELEPHONE CABLE LINE

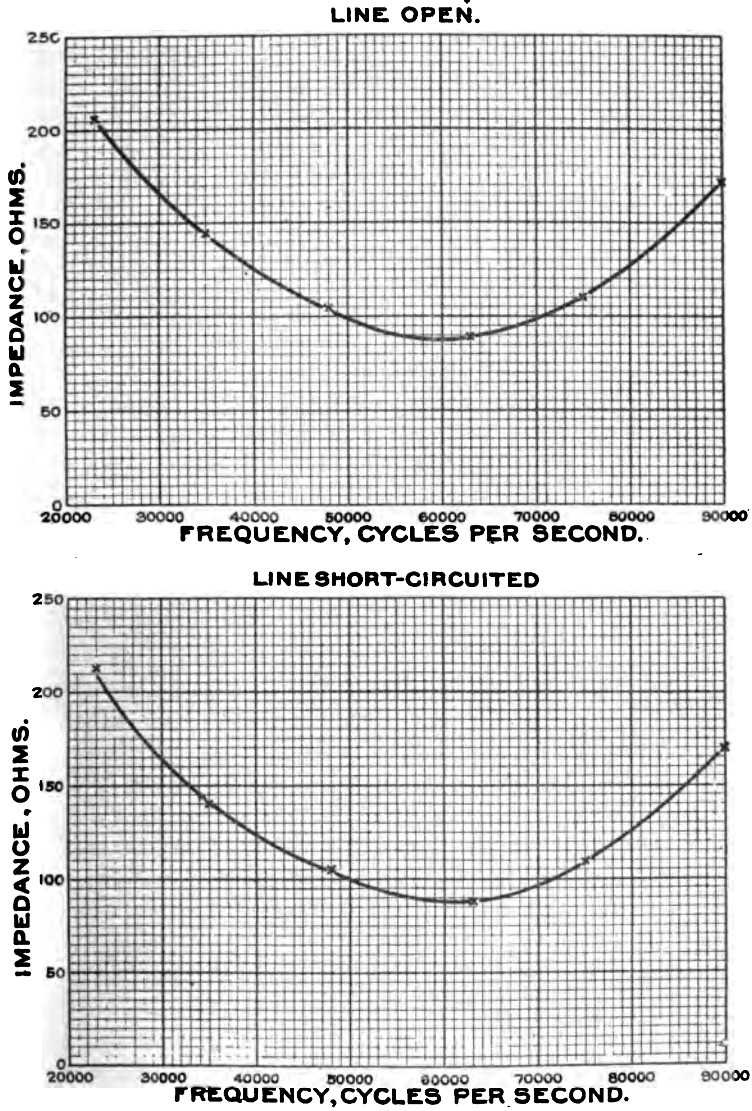


FIG. 20.

TRANSMITTING IMPEDANCE AT RESONANCE BY THE AMMETER-VOLTMETER METHOD.

To determine the general character of the effective impedance of this line as the frequency is changed, measurements were made of the transmitting current and voltage as the frequency is varied from about 23,000 to 90,000 cycles per second. The circuit is shown in figure 19 and the data obtained are given in Table X, which is shown graphically in figure 20. In taking these measurements loose coupling was used and the tuning elements adjusted to resonance in each case. The voltmeter used was of the hot-wire type of comparatively high resistance, and the ammeter was of the hot-wire type of low resistance. For resonance we have $I=\frac{E}{Z}$ or $Z=\frac{E}{I}$, where E and I are the measurements given above, from which Z in columns 4 and 7, Table X, has been derived. The curves, figure 20, indicate a minimum effective impedance of about 87 ohms at a frequency of about 59,000, the curves being nearly symmetrical on either side of this frequency.

Attempts were made to make similar measurements for the line connected directly to the generator instead of inductively connected as above and working to constant voltage at different frequencies. In such cases the reaction between the resonant circuit of the line and the directly connected circuit of the generator armature was so marked and so sensitive to variation of frequency at resonance that it was found extremely difficult to make consistent measurements under these conditions. The marked superiority of loose inductive coupling between the line circuit and the generator enabled a study to be made of the line circuit per se without involving any reactive influence from the generator source.

It is noteworthy that with this cable line it was not possible to detect with certainty the reactive influence of opening or closing the distant end of the line upon the transmitting voltmeter and ammeter readings, and, as noted above, the resonant curves at the transmitting end are practically the same for the distant end open or closed.

The presence in this line of two pairs of inductive heat coils at fixed points undoubtedly is sufficient to cause at least partial reflections of the waves being propagated along the line. These heat coils, as stated above, each had a measured inductance of 4,400 cms. at 70,000 cycles.

TABLE X.—*Data for transmitting end impedance at resonance of telephone cable line, receiving end open and short-circuited, at different frequencies.*

Cycles per second.	Line open.			Line short-circuited.		
	Volts.	Amperes.	Ohms.	Volts.	Amperes.	Ohms.
23,000	22.2	0.108	206	22.6	0.106	213
35,000	16.1	0.112	144	16.2	0.116	140
47,000	16.0	0.154	104	16.0	0.153	105
63,000	15.8	0.178	89	15.8	0.180	88
75,000	16.3	0.148	110	16.2	0.148	109
90,000	23.8	0.138	172	23.5	0.138	170

RESONANCE CURVE AT RECEIVING END.

In the series of resonance curves which has already been given, the observations were taken at the transmitting end of the cable line, and no attempt at tuning was made at the receiving end of the line, it being the object to study first the line per se without terminal apparatus. The effects, however, of introducing tuning elements across the line at the receiving end are strikingly shown in figure 21, the data for which are given in Table XI. In taking these observations a frequency of 40,000 was selected as fairly representative.

At the transmitting end of the line the current and frequency were kept constant throughout, and at the receiving end of the line only the capacity element of the tuning apparatus was varied, which caused a rise and fall of the received current, as shown in figure 21.

The inductance element of the tuning apparatus at the receiving end was kept constant throughout the experiment, so that the variables which are plotted in this curve are the actual observations taken and therefore represent exact conditions with no supposition as to derived results. It is noted that the magnitude of received current in this case can be easily multiplied nearly three times by simply adjusting the variable condenser at the receiving end, in a receiver arrangement selected at random.

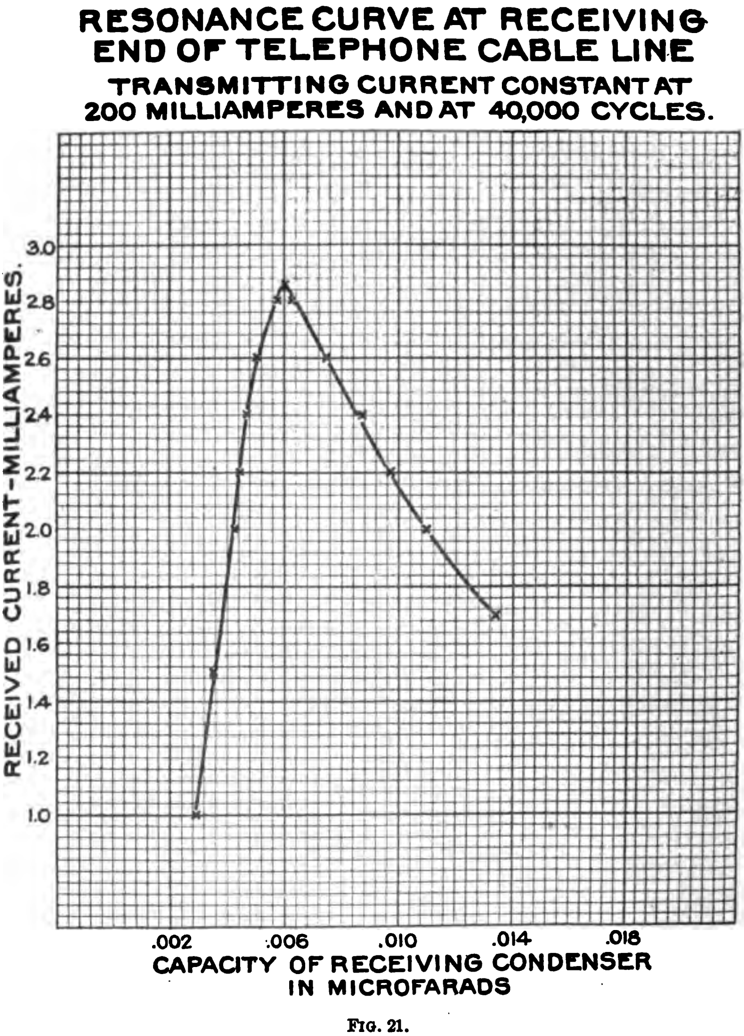

RESONANCE CURVE AT RECEIVING END OF TELEPHONE CABLE LINE
TRANSMITTING CURRENT CONSTANT AT 200 MILLIAMPERES AND AT 40,000 CYCLES.
RECEIVED CURRENT-MILLIAMPERES.
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.002
.006
.010
.014
.018
CAPACITY OF RECEIVING CONDENSER IN MICROFARADS

FIG. 21.

TABLE XI.—*Resonance curve at receiving end of telephone cable line. Transmitting current constant at 200 milliamperes and 40,000 cycles.*

Receiving capacity in microfarads in series with constant inductance.	Received current in milliamperes.
.00292	1.00
.00354	1.50
.00422	2.00
.00442	2.20
.00470	2.40
.00508	2.60
.00579	2.80
.00606	2.83
.00622	2.80
.00748	2.60
.00870	2.40
.00972	2.20
.01097	2.00
.01337	1.70

ATTENUATION-FREQUENCY CURVE AT RECEIVING END OF TELEPHONE CABLE LINE, SHORT-CIRCUITED THROUGH DUDDELL THERMOAMMETER OF 171 OHMS, TRANSMITTING CURRENT CONSTANT AT 240 MILLIAMPERES.

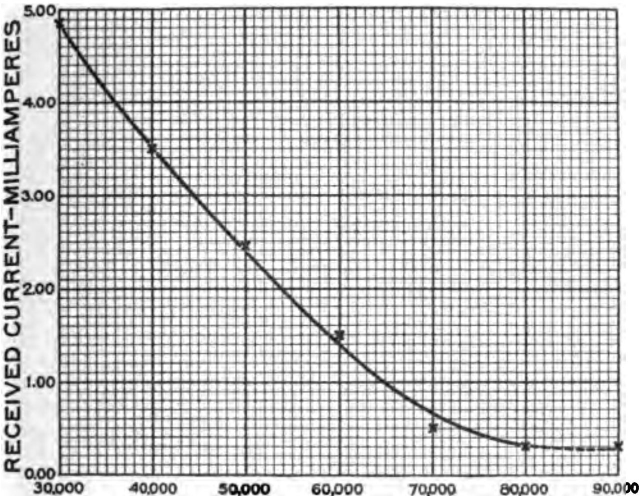


FIG. 22.

ATTENUATION CURVE.

To determine quantatively the influence of variation of frequency upon the attenuation of the current transmitted over this telephone line, the data given in Table XII was obtained, the curve for which is shown in figure 22.

In this experiment the transmitting current was kept constant at 240 milliamperes, the only thing varied being the frequency of the alternator.

At the receiving end the telephone line was short-circuited through a Duddell thermoammeter, which is practically non-inductive with a resistance of 171 ohms. The frequency was varied between 30,000 and 90,000 cycles per second, and observations were taken at intervals of 10,000 cycles per second. The curve shows very strikingly the attenuation of the transmitted current as the frequency is increased. The values of the received current at 80,000 and 90,000, being about as small as could be read on the particular ammeter used, are not as accurate as the other readings, and this is indicated by the dotted part of the curve.

TABLE XII.—*Data for attenuation-frequency curve at receiving end of telephone cable line, short-circuited through Duddell thermoammeter of 171 ohms, transmitting current constant at 240 milliamperes.*

Transmitting current in milliamperes.	Received current in milliamperes.	Frequency.
240	4.85	30,000
240	3.50	40,000
240	2.45	50,000
240	1.50	60,000
240	0.50	70,000
240	0.30	80,000
240	0.30	90,000

V. SUMMARY.

Radio-telegraphy has no competitor as a means of transmitting intelligence between ships at sea and between ships and shore stations, and on land it is also unique in its usefulness in reaching isolated districts and otherwise inaccessible points. To what extent it may be also developed to furnish practical intercommunication according to the high standard now enjoyed in thickly populated districts it is not attempted to predict.

The foregoing experiments indicate that either the existing wire system or additional wires for the purpose may be utilized for the efficient transmission of telephonic and telegraphic messages, and the former without interfering with the existing telephone traffic on these wires.

The fact that each of the circuits created by the use of superimposed high frequency methods is both a telephone and a telegraph circuit interchangeably, makes it possible to offer to the public a new type of service which, it is believed, will offer many advantages to the commercial world. This type of circuit should be particularly applicable to press-association service, railroad service, and leased-wire service of all kinds.

The experiments described should not be interpreted as in any way indicating limitations to radio telegraphy and telephony in the future, for their present rapid development gives justification for great prospect for the future. It is rather considered that the whole system of intercommunication, including both wire methods and wireless methods, will grow apace, and as each advance is made in either of these it will create new demands and standards for still further development. We need more wireless telegraphy everywhere, and not less do we need more wire telegraphy and telephony everywhere, and, again, more submarine cables. The number of submarine cables connecting Europe with America could be increased many times and all of them kept fully occupied, provided the traffic were properly classified to enable some of the enormous business which is now carried on by mail to be transferred to the quicker and more efficient cablegram letter. That time will surely come when the methods of electrical intercommunication will have been so developed and multiplied that the people of the different countries of the world may become real neighbors.

Accustomed to the methods of transmitting energy for power purposes by means of wire, it is a matter of wonder that enough energy can be delivered at a receiving antenna from a transmitting point thousands of miles distant to operate successfully receiving devices. The value of a metallic wire guide for the energy of the electric waves is strikingly shown in the above experiments, and it furnishes an efficient directive wireless system which confines the ether disturbances to closely bounded regions and thus offers a ready solution to the serious problems of interferences between messages which of necessity have to be met in wireless operations through space.

The distortion of speech, which is an inherent feature of telephony over wires, should be much less, if not practically absent, when we more and more withdraw the phenomenon from the metal of the wire and confine it to a longitudinal strip of the ether which forms the region between the two wires of a metallic circuit.

The ohmic resistance of the wire as shown can be made to play a comparatively unimportant part in the transmission of speech and the more the phenomenon is one of the ether, instead of that of metallic conduction, the more perfectly will the modified electric waves, which are the vehicle for transmitting the speech, be delivered at the receiving point without distortion.

It has been shown that the phenomena of resonance, which is met with in so many different branches of physics, exhibits very striking and orderly results when applied to electric waves propagated by means of wires. By utilizing this principle it has been shown that the receiving current at the end of the line may be built up and amplified many times over what it would be with untuned circuits.

The tuned electrical circuit at the receiving end readily admits electromagnetic waves of a certain definite frequency, and bars from entrance electromagnetic waves of other frequencies. This permits the possibility of utilizing a single circuit for multiplex telephony and telegraphy.

UNITED STATES SIGNAL CORPS
RESEARCH LABORATORY,
BUREAU OF STANDARDS.
Washington, D. C., January, 1911.

APPENDIX

[United States Patents, Numbers 980,356, 980,357, 980,358, and 980,359.]

UNITED STATES PATENT OFFICE.

GEORGE OWEN SQUIER, OF THE UNITED STATES ARMY.

MULTIPLEX TELEPHONY AND TELEGRAPHY.

980,356. Specification of Letters Patent. **Patented Jan. 3, 1911.**

Application filed November 5, 1910. Serial No. 590,801.

(Dedicated to the public.)

To all whom it may concern:

Be it known that I, George Owen Squier, major in the Signal Corps, U. S. Army, a citizen of the United States, and residing at Washington, District of Columbia, (whose post-office address is War Department, Washington, District of Columbia,) have invented certain new and useful Improvements in Multiplex Telephony and Telegraphy, of which the following is a specification.

This application is made under the act of March 3, 1883, chapter 143, (U. S. Statute XXII, p. 625,) and the invention herein described and claimed may be used by the Government of the United States or any of its officers or employees in the prosecution of work for the United States or by any person in the United States without the payment of any royalty thereon.

This invention relates to multiplex telephony and telegraphy and has as its object the simultaneous transmission of a plurality of telephonic and telegraphic messages over a single telephonic circuit.

A further object of the invention is the disposition of the various elements in such a manner as to eliminate all "cross-talk" or other harmful effects of one message upon another.

A further object is to impress electric waves or oscillations of such different frequencies upon the circuit as to make possible the selection and complete independence of the various messages.

A further object is to superimpose upon a standard battery telephone circuit, as now commercially used, one or more additional telephonic and telegraphic circuits without any interference of the various messages.

In accomplishing the above results use is made of electromagnetic waves or oscillations of high frequency guided by wires.

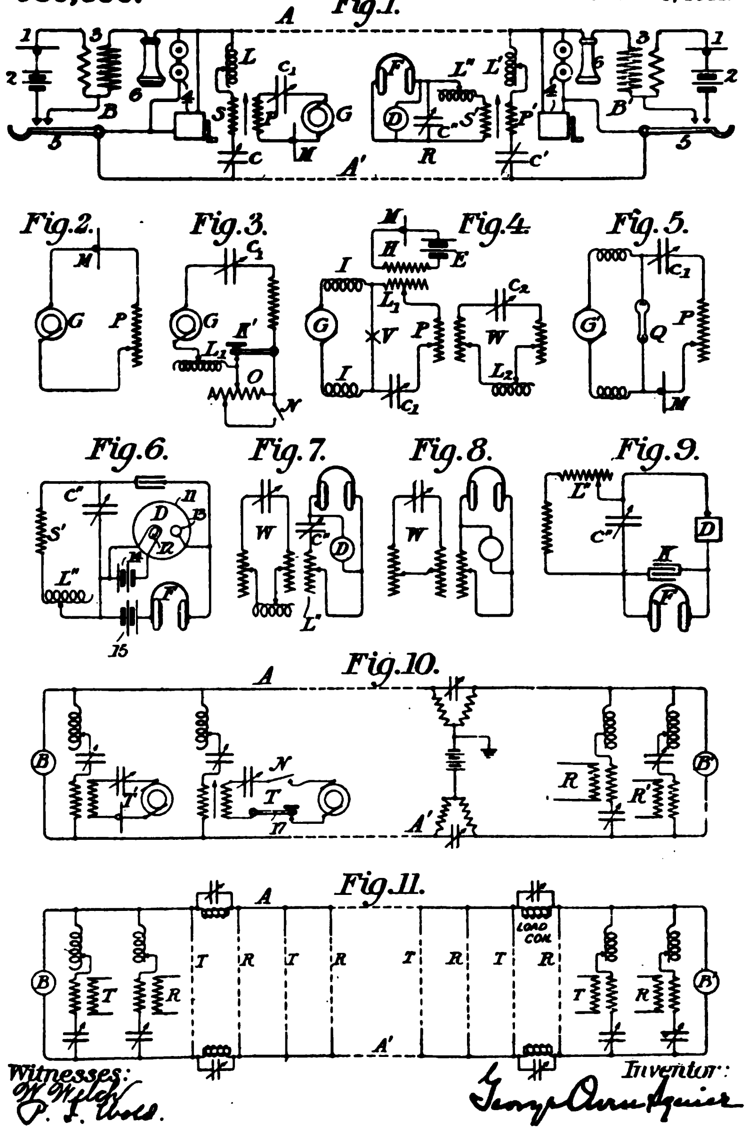
In the whole range of electromagnetic waves, which may be looked upon as a spectrum extending from the ultra-violet rays on the one hand to the exceedingly slow oscillations, such as are used on long submarine cables,

G. O. SQUIER.

MULTIPLEX TELEPHONY AND TELEGRAPHY.

APPLICATION FILED NOV. 8, 1910

980,356. Patented Jan. 3, 1911.



on the other hand, use has been made of all parts for various purposes with the exception of two well defined intervals, one extending from a frequency of about 3×10^{12} of the extreme infra-red, to 5×10^{10}, which are the shortest electromagnetic waves yet produced by electrical apparatus,—and another interval extending from about 100,000 cycles per second to about 15,000 to 20,000 cycles per second. This latter range of frequencies represents a practically unexplored field which I have found by experiment to be very useful in solving the problems of multiple telephony and telegraphy upon wire circuits.

When reference is made in this application to high frequency waves or oscillations, it is understood to mean oscillations with a frequency above human audition, or ultra-sound frequencies.

The limit of audibility being a physiological function is well known to vary considerably, but it is in the neighborhood of 15,000 to 20,000 cycles per second.

By employing ultra-sound electromagnetic wave frequencies as the vehicle for transmitting telephonic and telegraphic messages, it is evident that all harmful effects to any element of the battery telephone apparatus are immediately removed, since not only are any such effects very minute, in character, by virtue of the high period of the oscillations, but also, even if there were any effects in the telephone receiver, or transmitter, or any other part of the apparatus, it could not be detected by a human being, since the natural limitations of the ear afford a most effective and sure separation between all frequencies above 15,000 to 20,000 per second on the one hand, and all frequencies below 15,000 to 20,000 and down to about 16 per second, which is the lower limit of audibility. Therefore, a fundamental principle of this system may be said to be, from one view-point, the utilization of this unalterable characteristic of the human ear.

With such frequencies as are used in ordinary battery telephony the so-called phenomenon of "skin effect" is comparatively small, and the current is fairly well distributed throughout the cross-section of the conductor. As the frequency increases the skin effect becomes more pronounced and the energy appears to be more and more transmitted or stored in the ether surrounding the conductor. For this reason the battery telephone current is largely a conduction current through metal, and the ohmic resistance of the wire is one of the principal elements which limits long distance telephony at present, whereas in commercial wireless telegraphy, in which frequencies from 100,000 up to several millions are used, the impressed energy is chiefly radiated into the ether.

In the intermediate range from say 20,000 to 100,000 and above the energy is largely carried by the ether, but is still sufficiently linked to the conductor to prevent excessive radiation into the ether. The conductor while carrying but a small part of the energy at its surface nevertheless acts as an efficient guide for the high frequency electromagnetic waves. In accordance with these principles, use is made of these efficiently guided electromagnetic ether waves as a vehicle to carry the telephonic or telegraphic message.

In accomplishing the above it has been found necessary and sufficient to combine the engineering practice of wireless telegraphy and telephony with the engineering practice of wire telegraphy and telephony. Since wireless engineering deals with frequencies much higher than ordinary telephony it is obvious that different dimensions for capacities and inductances must be used, for instance, whereas the ordinary telephonic practice makes use of condensers with capacity of several microfarads it is here necessary to use capacities of the order of magnitude of thousandths of a microfarad and inductances of millihenries.

The present invention makes use of the types of apparatus, engineering methods, etc., now practiced in the wireless art and applies them to the transmission of electromagnetic waves along wires, with the result of an enormous increase in efficiency of such transmission over the ordinary method employing antennæ at transmitting and receiving stations. The circuits employed in this invention are ordinary telephonic circuits, such as now used in wire telephony and telegraphy, and are very poor radiators of electromagnetic energy; in fact, the regular twisted-pair paper-insulated lead-covered telephonic cable affords a circuit for such electromagnetic waves which produce a very closely bounded system and the energy is principally conveyed in such a circuit in the minute layer of ether separating the two metallic conductors. In this manner, and by these means, a most efficient system of directive high frequency telegraphy and telephony is attained, and also any interferences between neighboring circuits operated by this system is eliminated, so that a plurality of such circuits may be brought to the same switchboard with no harmful interfering effects.

It is old in the art to use high frequency oscillations and modify these in accordance with speech vibrations by effecting some electromagnetic constant or constants of the circuit in which the oscillations take place. It is possible to change the capacity, the inductance or the resistance of such a circuit or combinations of these, and while I do not wish to limit myself to any one of these, I have found that it is very convenient and effective to change the resistance by a suitable telephone transmitter such as a microphone transmitter of the usual type employed in ordinary telephonic work. Having modified these oscillations suitably they are transmitted over the line to a receiving station where they are then received in a suitable selective circuit containing a detector for high frequency oscillations, any detector, such as used in wireless telegraphy and telephony, being satisfactory so long as it is a quantitative or integrating detector. By means of suitable translating means the oscillations are then transformed into telephonic currents, all of which is described more in detail hereafter.

Since a plurality of high frequency waves of different frequencies may be impressed on the same line, and since these may be selectively separated from each other by suitably tuned circuits, it is obvious that multiplex telephony may be accomplished. Also, for the reasons stated above, it has been found that these high frequency waves may exist on the same line with ordinary battery telephone currents without in any way affecting them, and thus this system of multiplex telephony may be applied to the usual telephonic circuits without the presence of harmful effects, such as "cross-talk" or other disturbances.

It has been found necessary, in order to obtain efficient results, to make use of such detectors as are commonly found in the wireless telegraphic art. Attempts have been made at multiplex telephony, but I have found these inoperative, for the reason, among others, that no detector or equivalent device has been used. These detectors are not used because of any greater sensitiveness to electrical energy than resides in the telephone receiver itself, but because the energy, being in the form of rapid oscillations, cannot affect the telephone or other indicating device. These rapid oscillations cannot sensibly affect the telephone because the diaphragm in its motion must reverse with the reversal of the current and the deflecting impulse if applied directly to the telephone receiver will be first in one direction and then in the other with a frequency so high that the diaphragm cannot follow or respond. Furthermore, if the diaphragm should respond with this frequency the effect would not be audible. Also, in the case of the ordinary telephone, on account of the large self-inductance of the instrument, the high frequency E. M. F. generated by the waves would produce in a telephone receiver only extremely weak currents. I have found it necessary, therefore, and consider it an important part of my invention to make use of some form of integrating detector to transform these rapid oscillations into effects which can be manifested by the indicating instrument.

In the drawings forming a part of this specification several modifications for the circuit connections are shown, and Figure 1 illustrates a form of circuit in which the high frequency oscillatory telephonic messages are impressed on the line by a bridge connection. Figs. 2 to 5 illustrate modifications of various transmitting circuits. Figs. 6 to 9 illustrate various receiving circuits. Figs. 10 and 11 illustrate modifications of the connections shown in Fig. 1.

Referring to these figures in detail, Fig. 1 shows a common metallic circuit for ordinary telephony, across which are bridged the ordinary telephone sets B and B′. These telephone sets include the usual apparatus as in present use in local battery telephone circuits, there being shown a microphone transmitter 1 with its local battery 2 and the primary of the transformer 3. Also, there is shown connected in the usual way the ringing circuit 4 and the switchhook 5 with its receiver 6. The secondary of the transformer 3 is bridged directly across the line wires A and A′ when the receiver is off the hook.

The invention is not in any way connected with the details of this telephone connection, any of the usual circuit connections being suitable, and the one described being given merely as an illustration.

Bridged across the line wires A and A′ at the same terminals or at any convenient distance from the terminals of the common battery telephone there is bridged a circuit containing a variable inductance L, variable capacity C, and the secondary S of a transformer. The primary P of the transformer is in circuit with a generator G of high frequency oscillations, and in circuit with the generator is also included a variable capacity C_1, and a suitable telephone transmitter, such as a microphone transmitter M. The transformer above mentioned is so constructed as to be variable in its coupling, either by sliding one coil within the other, varying the angle between the planes of the coils, or by any other suitable well known arrangement. At the receiving end of the line there is bridged a similar circuit containing a variable inductance L′ and variable condenser C′ and the primary P′ of a transformer. The secondary S′ of this transformer is connected in series with a variable inductance L″ and a variable condenser C″, and around the condenser is shunted a detector D of the type commonly used in wireless telegraphy. In circuit with the detector is connected, in the usual way, the telephone receiver, as shown at F.

The operation of the device is as follows: High frequency oscillations developed by the generator are impressed on the bridge circuit containing the inductance L and capacity C, which oscillations then travel along the line wires A and A′ and are received in the receiver R containing the oscillatory circuit L″ C″. If these oscillations are modified in any suitable manner, an effect is immediately produced in the receiver.

While various means may be adopted to give the necessary variations to high frequency currents, I have found it effective and convenient to place in the circuit of the generator, or in the line itself, a microphone transmitter M, which produces on the sustained oscillations of high frequency slight modifications in amplitude of comparatively slow period, but corresponding in every detail with the ordinary voice vibrations. These modified oscillations when received at R and transformed by the detector give a reproduction in the telephone receiver F of speech transmitted from the generator circuit. Since these oscillations are of such high frequency they will produce no effect whatsoever in the battery sets B and B′, for the impedance of these sets is so high for these frequencies as to entirely prevent their passage. Furthermore, any telephonic currents transmitted by either of the sets B and B′ will travel over the line wires at the same time as the high frequency currents, but they will in no way be influenced by, nor will they exert any sensible influence upon the high frequency currents. It has been found desirable in practice to tune the circuit comprising the line and bridges to the frequency of the generator by means of the variable inductances L and L′ and the variable capacities C and C′. The condensers C and C′ are also useful in preventing the passage of any telephonic currents from the sets B through the high frequency bridge circuit, for these condensers are of exceedingly small capacity, being measured in thousandths of a microfarad, and thus interpose too large an impedance for currents of ordinary telephonic frequencies. These condensers, however, when taken in connection with the inductances L and L′, interpose a low impedance to the oscillations of such high frequencies as lie above 20,000 per second.

Under certain conditions it may be desirable to have in series with the telephone sets B and B′ suitable inductance coils, which will be of such dimensions as to prevent the passage of the high frequency oscillations, but which interpose only small impedance to the ordinary telephonic currents. In practice, however, this is found to be unnecessary, for the telephones themselves contain sufficient impedance for the purpose.

Various forms of generator connections may be used as shown, for example, in Figs. 2 to 5. In Fig. 2 there is shown the generator G in series with the microphone transmitter M and a variable primary P of a transformer. This circuit, as a whole, may be substituted, if desired, for the transmitter circuit shown in Fig. 1. For more carefully selected tuning, it is sometimes desirable to use the form of transmitter connection shown in Fig. 3, in which there is included a condenser C_1 and the variable inductance L_1. In case the generator is limited in power, it is desirable to use the circuit shown in Fig. 3, having the same tuned to the frequency of the generator. In Fig. 4 there is shown still another form of generator circuit. In this case the Duddell arc V is supplied with energy from the direct current generator G′ through the choke coils I. Around the arc there is shunted an oscillatory circuit containing a variable capacity C_1 and a variable inductance L_1 in series with the primary of a transformer P. This generator circuit may then be connected inductively to the bridge across the line wires, or, if desired, a weeding-out circuit W may be interposed. This weeding-out circuit is well understood in the art, being made up of a variable condenser C_2 in series with a variable inductance L_2 and the necessary transformer coils as shown in Fig. 4. As shown in this figure, the telephonic variation in the oscillations may be introduced by means of a secondary circuit H containing a microphone or other suitable transmitter M and battery E and a primary of a transformer, said primary being inductively connected to the inductance L_1. This inductive method of modifying the oscillations may be used in the form of circuits shown in Figs. 1, 2, 3 and 5. In Fig. 5 still another form of generator of oscillations is shown, this generator consisting of a mercury vapor lamp connected in series with the D. C. generator G′ and suitable choke coils, the lamp being shunted by a capacity and inductance of an oscillatory circuit in the well known manner. Oscillations may then be modified by a microphone transmitter M in any suitable manner as described above.

In Figs. 6 to 9 there are shown modifications of the receiver circuit, and it is to be understood that any one of these circuits may, if desired, be substituted for the one shown in Fig. 1. All of these circuits are such receiving circuits as are well known in the art of wireless telegraphy and telephony and are described here but briefly. Fig. 6 shows the receiving oscillatory circuit consisting of the variable inductance L″, variable capacity C″ and the secondary S′ of the transformer. This circuit is tuned to the frequency of the oscillations developed by the generator G. In shunt to the condenser is placed the detector D, which is of some high resistance type, such as the audion or the perikon detector. Other well known types are equally useful in this relation. In shunt to the detector is shown the telephone receiver F, with or without battery as may be desired. In Fig. 7 there is shown, in connection with the detector circuit, a weeding-out circuit W of a well known type. It is noted that in Fig. 7 the detector is connected directly in series with an oscillatory circuit containing the condenser C″ and inductance L″, this being a suitable connection only in case the detector is of a low resistance type. As shown in Fig. 8, it may not be necessary to have the detector circuit tuned when use is made of the weeding-out circuit W. Fig. 9 shows still another form of receiver circuit, the oscillations being set up in a circuit containing the inductance L″ and capacity C″. Around the condenser is shunted a detector D, such as the perikon detector in series with a capacity K of fairly large electrical dimensions. In shunt to the condenser K is the telephone receiver F.

Although numerous types of detectors have been used, I have found the audion an exceedingly useful type, for it requires very little attention in the way of adjustments. The connection of this audion is shown clearly in Fig. 6, in which the exhausted bulb 11 contains the filament 12 and the electrode 13. The filament 12 is heated by the battery 14, and connected to the filament and the electrode 13, as shown in the figure, is the telephone receiver F and the battery 15.

Referring now to Fig. 10: It has been found possible to bridge across the line circuit A and A′ a plurality of high frequency circuits, each one similar in every respect to that described in Fig. 1. Preferably, the generators differ from each other in frequency and differ by such an amount as to allow easy selective tuning. It is apparent that these two high frequency oscillation generators, shown in Fig. 10, will be entirely independent of each other in the above properly tuned circuits, so that the oscillations, although existing together on the line, will be properly separated and selected at the receiving stations, that frequency generated at the transmitter T being selected by the receiver R. The local circuit and each pair of bridge circuits with the line are tuned to the same frequency and to the frequency of the generator T. Also the receiver R′ is tuned to the same frequency as the generator T′. It is obvious, in connection with this, that telegraphic messages may be transmitted as well as telephonic messages. This is illustrated in the transmitter at T, in which the microphone transmitter is replaced by the interrupter N and the telegraphic key 17, this key being shown in detail in Fig. 3. In said Fig. 3 there is shown the key K′, around which is shunted a variable resistance or inductance O. A variable portion of this element O is shunted by the interrupter N. This avoids the necessity of completely breaking the generator current, and the signals are made merely by modifying the oscillations with a definite frequency. Obviously, many modifications of this key may be used. This form of telegraph transmitter may obviously be substituted for any of the telephone transmitters. By means of this system it is possible to transmit simultaneously the ordinary telephonic speech by means of the sets B and B′ and high frequency telephonic messages by means of the transmitter T′, and also telegraphic messages by means of the transmitter T.

In Fig. 11 there is shown a still further modification, in which a plurality of transmitters and receivers are bridged across the line. In this Fig. 11 the generator circuits T are indicated only diagrammatically by the coil of wire, it being understood that this represents any of the transmitters shown in Figs. 2 to 5. The receivers are shown at R and only diagrammatically, it being understood that any of the receivers shown in Figs. 6 to 9 being useful in this connection. Obviously, it is possible and desirable to have some of these transmitters at one end of the line and the others at the other end, as indicated by the reference letters T and R. The receivers may be placed some at one end and some at the other, and in practice it would ordinarily be convenient to have the same number of transmitters and receivers at each end. It is of course understood that each transmitter has a frequency of its own, and that one receiver and its bridging circuit with the line are tuned to the frequency corresponding to their transmitter. All of these high frequency currents may exist upon the line simultaneously and have no perceptible effect upon each other, nor will they have any sensible effect whatsoever upon the ordinary battery telephonic currents transmitted in the usual way.

In Figs. 10 and 11 the telephone sets B are merely indicated, it being understood that such a set as is shown in Fig. 1 is to be used.

It may be desirable in certain cases to omit the ordinary battery telephonic sets entirely, in which case the multiplex telephony would be carried on entirely by high frequency currents of different periods.

In case a common battery telephone circuit is used, instead of local battery sets as shown, it will be necessary to shunt the repeating coils by variable condensers of such small capacity as to offer a high impedance to ordinary telephone currents but low impedance to the high frequency oscillations. Also, in case of loading coils or other high inductances, it will be necessary to put in similar shunt condensers.

The generators here described have a single period, but it is obvious that use may be made of multiperiod generators, in which case the individual frequences from said generators would be used in separate transmitter circuits.

Although several modifications have been described in detail in this specification, it is obvious that many other changes may be made without departing from the spirit of the invention, and I therefore do not wish to be limited to the exact connections shown, but

What I claim as my invention is the following:

1. In a multiplex telephone and telegraph system, the combination of a pair of line wires, battery telephone sets bridged across said line wires; means at one end for impressing high frequency oscillations on said line wires; means for modifying said oscillations in accordance with speech; means at the other end for detecting said oscillations the complete circuit for the high frequency oscillations being tuned to the frequency of the oscillations.

2. In a multiplex telephone and telegraph sytem, the combination of a pair of line wires, battery telephone sets bridged across said line wires; a generator of high frequency electric waves or oscillations inductively connected to said line wires, means for modifying the oscillations; a receiver circuit inductively connected to the line wires and tuned to the frequency of the generator, an integrating detector in said receiver circuit and a telephone operatively connected thereto.

3. In a multiplex telephone and telegraph system, the combination of a pair of line wires, a plurality of generators of high frequency oscillations inductively connected to said line wires, means in each generator circuit for modifying the oscillations; a plurality of receiver circuits inductively connected to the line wires, each receiver circuit being tuned to the frequency of one of the generators, an integrating detector in each receiver circuit and a telephone operatively connected to each detector.

4. In a multiplex telephone and telegraph system, the combination of a pair of line wires, battery telephone sets bridged across said line wires, a generator of high frequency oscillations, a signaling instrument for modifying the high frequency oscillations, said generator being inductively connected to a circuit bridged across the line wires at one end thereof, a similar circuit bridged across the circuit at the other end and a receiver circuit inductively connected thereto, said bridges with the line wires being tuned to the frequency of the generator.

5. In a multiplex telephone system, the combination of a pair of line wires, a battery telephone set bridged across said line wires at each end thereof, a generator of oscillations of a frequency above the limit of audibility, a telephone transmitter for modifying the high frequency oscillations, said generator being inductively connected to a circuit bridged across the line wires at one end thereof; a similar circuit bridged across the line at the other end, and a receiver circuit inductively connected to said last named bridge circuit, said bridge circuits with line wires being tuned to the frequency of the generator.

6. In a multiplex telephone system, the combination of a pair of line wires, battery telephone sets bridged across said line wires, a generator of high frequency oscillations, a microphone transmitter for modifying the high frequency oscillations, said generator being inductively connected to a circuit bridged across the line wires at one end thereof, said bridging circuit comprising a condenser and an inductance in series with the secondary of a transformer; a similar circuit bridged across the line at the other end and a receiver circuit inductively connected thereto, said bridge circuits with line wires being tuned to the frequency of the generator.

7. In a multiplex telephone system, the combination of a pair of line wires, a battery telephone set bridged across said line wires at each end thereof, a generator of high frequency oscillations, a microphone transmitter for modifying the high frequency oscillations, said generator being inductively connected to a circuit bridged across the line wires at one end thereof, said bridging circuit comprising a condenser and an inductance in series with the secondary of a transformer; a similar circuit bridged across the line at the other end and a receiver circuit inductively connected thereto, said receiver circuit being tuned by means of a capacity and inductance to the frequency of the generator and said receiver circuit including a detector of high frequency oscillations, and a telephone receiver operatively connected to said detector.

8. In a multiplex telephone and telegraph system, the combination of a pair of line wires, battery telephone sets bridged across said line wires, a plurality of circuits bridged across the line wires, each circuit including a variable capacity and inductance; a plurality of sources of high frequency oscillations, one inductively connected to each of the bridge circuits, a signaling instrument in circuit with each source of oscillations to modify the said oscillations, a plurality of similar circuits bridged across the line and a plurality of receiver circuits, one inductively connected to each of the bridge circuits, each receiver circuit and each pair of bridge circuits with the line wires being tuned to the frequency of the corresponding generator.

9. In a multiplex telephone system, the combination of a pair of line wires, a battery telephone set bridged across said line wires at each end thereof, a plurality of circuits bridged across the line wires, each circuit including a variable capacity and inductance; a plurality of sources of high frequency oscillations, one inductively connected to each of the bridge circuits, a signaling instrument in circuit with each source of oscillations to modify the said oscillations, a plurality of similar circuits bridged across the line and a plurality of receiver circuits, one inductively connected to each of the bridge circuits, each pair of bridge circuits with the line and the cor-

responding receiver circuit being tuned to the frequency of one of the transmitter circuits, each receiver circuit containing a detector of high frequency oscillations and having a telephone receiver operatively connected thereto.

10. In a multiplex telephone system, the combination of a pair of line wires, a plurality of circuits bridged across the line wires, each circuit including a variable capacity and inductance for tuning, a plurality of sources of high frequency oscillations, one inductively connected to each of the bridge circuits, a signaling instrument in circuit with each source of oscillations to modify the said oscillations, a plurality of similar circuits bridged across the line and a plurality of receiver circuits, one inductively connected to each of the bridge circuits, each pair of bridge circuits with the line and the corresponding receiver circuit being tuned to the frequency of one of the transmitter circuits, each receiver circuit containing a detector of high frequency oscillations and having a telephone receiver operatively connected thereto.

11. In a multiplex telephone system, the combination of a pair of line wires, battery telephone sets bridged across said line wires, a plurality of local transmitter circuits, each circuit including a high frequency dynamo in series with a variable capacity, a variable inductance, a signaling instrument and the primary of a transformer; a plurality of local receiver circuits, comprising a variable condenser in series with a variable inductance and the secondary of a transformer coil, a vacuum detector shunted around said condenser and a telephone head-piece operatively connected to said vacuum detector; a plurality of bridging circuits connected across the line wires, each circuit containing a variable capacity and a variable inductance for tuning; a bridging circuit inductively connected to each transmitter circuit; a bridging circuit inductively connected to each receiver circuit, each pair of bridging circuits with the line and its corresponding receiver circuit being tuned to the frequency of the corresponding transmitter circuit, said plurality of transmitter stations and receiver stations being distributed along the line wire.

George Owen Squier.

Witnesses:
P. I. Wold,
E. R. Cram.

UNITED STATES PATENT OFFICE.

GEORGE OWEN SQUIER, OF THE UNITED STATES ARMY.

MULTIPLEX TELEPHONY AND TELEGRAPHY.

980,357. Specification of Letters Patent. Patented Jan. 3, 1911.

Application filed November 5, 1910. Serial No. 590,802.

(Dedicated to the public.)

To all whom it may concern:

Be it known that I, George Owen Squier, major in the Signal Corps, U. S. Army, a citizen of the United States, and residing at Washington, District of Columbia, (whose post-office address is War Department, Washington, District of Columbia,) have invented certain new and useful Improvements in Multiplex Telephony and Telegraphy, of which the following is a specification.

This application is made under the act of March 3, 1883, chapter 143, U. S. Statute XXII, p. 625,) and the invention herein described and claimed may be used by the Government of the United States or any of its officers or employees in the prosecution of work for the United States or by any person in the United States without the payment of any royalty thereon.

This invention relates to multiplex telephony and telegraphy and has as its object the simultaneous transmission of a plurality of telephonic and telegraphic messages over a single telephonic circuit.

A further object of the invention is the disposition of the various elements in such a manner as to eliminate all "cross-talk" or other harmful effects of one message upon another.

A further object is to impress electric waves or oscillations of such different frequencies upon the circuit as to make possible the selection and complete independence of the various messages.

A further object is to superimpose upon a standard battery telephone circuit, as now commercially used, one or more additional telephonic and telegraphic circuits without any interference of the various messages.

In accomplishing the above results use is made of electromagnetic waves or oscillations of high frequency guided by wires.

In the whole range of electromagnetic waves, which may be looked upon as a spectrum extending from the ultra-violet rays on the one hand to the exceedingly slow oscillations, such as are used on long submarine cables, on the other hand, use has been made of all parts for various purposes with the exception of two well defined intervals, one extending from a frequency of about $3x10^{12}$ of the extreme infra-red, to $5x10^{10}$, which are the shortest electromagnetic waves yet produced by electrical apparatus,—and another interval extending from about 100,000 cycles per second to about 15,000 to 20,000 cycles per second. This latter range of frequencies represents a practically unexplored field which I have found by experiment to be very useful in solving the problems of multiple telephony and telegraphy upon wire circuits.

G. O. SQUIER.

MULTIPLEX TELEPHONY AND TELEGRAPHY.

APPLICATION FILED NOV. 5, 1910.

980,357. **Patented Jan. 3, 1911.**

Fig.1.

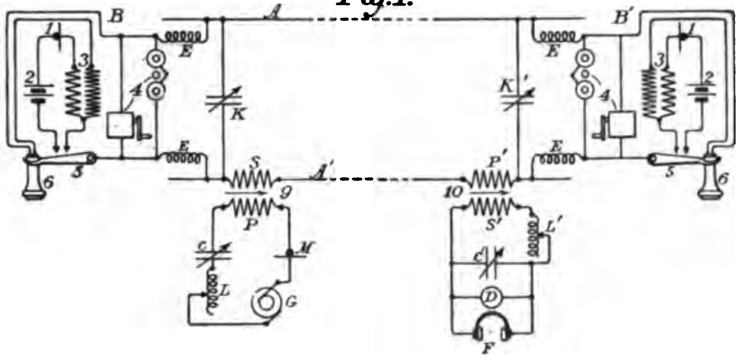


Fig.2.

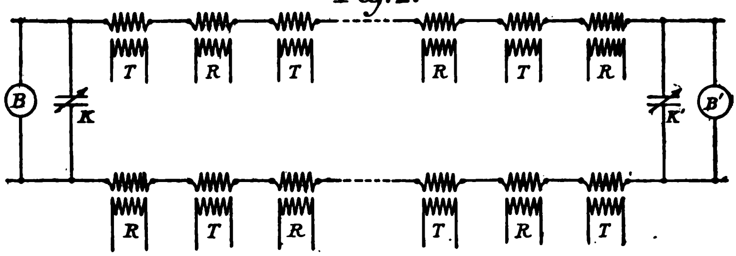
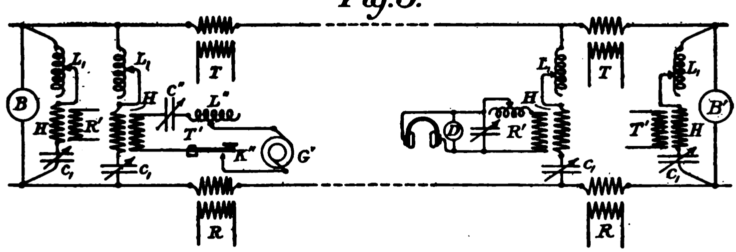


Fig.3.



Witnesses

Roy C. Bowen.

Inventor

George Owen Squier

When reference is made in this application to high frequency waves or oscillations, it is understood to mean oscillations with a frequency above human audition, or ultra-sound frequencies.

The limit of audibility being a physiological function is well known to vary considerably, but it is in the neighborhood of 15,000 to 20,000 cycles per second.

By employing ultra-sound electromagnetic wave frequencies as the vehicle for transmitting telephonic and telegraphic messages, it is evident that all harmful effects to any element of the battery telephone apparatus are immediately removed, since not only are any such effects very minute, in character, by virtue of the high period of the oscillations, but also, even if there were any effects in the telephone receiver, or transmitter, or any other part of the apparatus, it could not be detected by a human being, since the natural limitations of the ear afford a most effective and sure separation between all frequencies above 15,000 to 20,000 per second on the one hand, and all frequencies below 15,000 to 20,000 and down to about 16 per second, which is the lower limit of audibility. Therefore, a fundamental principle of this system may be said to be, from one viewpoint, the utilization of this unalterable characteristic of the human ear.

With such frequencies as are used in ordinary battery telephony the so-called phenomenon of "skin effect" is comparatively small, and the current is fairly well distributed throughout the cross-section of the conductor. As the frequency increases the skin effect becomes more pronounced and the energy appears to be more and more transmitted or stored in the ether surrounding the conductor. For this reason the battery telephone current is largely a conduction current through metal, and the ohmic resistance of the wire is one of the principal elements which limits long distance telephony at present, whereas in commercial wireless telegraphy, in which frequencies from 100,000 up to several millions are used, the impressed energy is chiefly radiated into the ether.

In the intermediate range from say 20,000 to 100,000 and above the energy is largely carried by the ether, but is still sufficiently linked to the conductor to prevent excessive radiation into the ether. The conductor while carrying but a small part of the energy at its surface nevertheless acts as an efficient guide for the high frequency electromagnetic waves. In accordance with these principles, use is made of these efficiently guided electromagnetic ether waves as a vehicle to carry the telephonic or telegraphic message.

In accomplishing the above it has been found necessary amd sufficient to combine the engineering practice of wireless telegraphy and telephony with the engineering practice of wire telegraphy and telephony. Since wireless engineering deals with frequencies much higher than ordinary telephony, it is obvious that different dimensions for capacities and inductances must be used, for instance, whereas the ordinary telephonic practice makes use of condensers with capacity of several microfarads it is here necessary to use capacities of the order of magnitude of thousandths of a microfarad and inductances of millihenries.

The present invention makes use of the types of apparatus, engineering methods, etc., now practiced in the wireless art and applies them to the transmission of electromagnetic waves along wires, with the result of an enormous increase in efficiency of such transmission over the ordinary method employing antennæ at transmitting and receiving stations. The circuits employed in this invention are ordinary telephonic circuits, such as now used in wire telephony and telegraphy, and are very poor radiators of electromagnetic energy; in fact, the regular twisted-pair paper-insulated lead-covered telephonic cable affords a circuit for such electromagnetic waves which produce a very closely bounded system and the energy is principally conveyed in such a circuit in the minute layer of ether separating the two metallic conductors. In this manner, and by these means, a most efficient system of directive high frequency telegraphy and telephony is attained, and also any interference between neighboring circuits operated by this system is eliminated, so that a plurality of such circuits may be brought to the same switch board with no harmful interfering effects.

It is old in the art to use high frequency oscillations and modify these in accordance with speech vibrations by affecting some electromagnetic constant or constants of the circuit in which the oscillations take place. It is possible to change the capacity, the inductance or the resistance of such a circuit or combinations of these, and while I do not wish to limit myself to any one of these, I have found that it is very convenient and effective to change the resistance by a suitable telephone transmitter such as a microphone transmitter of the usual types employed in ordinary telephonic work. Having modified these oscillations suitably they are transmitted over the line to a receiving station where they are then received in a suitable selective circuit containing a detector for high frequency oscillations, any detector, such as used in wireless telegraphy or telephony, being satisfactory so long as it is a quantitative or integrating detector. By means of suitable translating means the oscillations are then transformed into telephonic currents, all of which is described more in detail hereafter.

Since a plurality of high frequency waves of different frequencies may be impressed on the same line and since these may be selectively separated from each other by suitably tuned circuits, it is obvious that multiplex telephony may be accomplished. Also, for the reasons stated above, it has been found that these high frequency waves may exist on the same line with ordinary battery telephone currents without in any way affecting them, and thus this system of multiplex telephony may be applied to the usual telephonic circuits without the presence of harmful effects, such as "cross-talk" or other disturbances.

It has been found necessary, in order to obtain efficient results, to make use of such detectors as are commonly found in the wireless telegraphic art. Attempts have been made at multiplex telephony, but I have found these inoperative for the reason, among others, that no detector or equivalent device has been used. These detectors are not used because of any greater sensitiveness to electrical energy than resides in the telephone receiver itself, but because the energy, being in the form of rapid oscillations, cannot affect the telephone or other indicating device. These rapid oscillations cannot sensibly affect the telephone because the diaphragm in its motion must reverse with the reversal of the current and the deflecting impulse if applied directly to the telephone receiver will be first in one direction and then in the other with a frequency so high that the diaphragm cannot follow or respond. Furthermore, if the diaphragm should respond with this frequency the effect would not be audible. Also, in the case of the ordinary telephone, on account of the large self-inductance of the instrument, the high frequency E. M. F. generated by the waves would produce in a telephone receiver only extremely weak currents. I have found it necessary, therefore, and consider it an important part of my invention to make use of some form of integrating detector to transform these rapid oscillations into effects which can be manifested by the indicating instrument.

In the drawings forming a part of this specification several modifications for the circuit connections are shown.

This application is closely related to my co-pending application, Serial Number 590,801, filed November 5, 1910, in this, that use is made of high frequency electromagnetic waves or oscillations to act as a vehicle for the telephone or telegraph messages which oscillations are impressed upon the same line as carries the telephonic currents from an ordinary local battery telephone set. This application differs from said co-pending application essentially in this, that the various sources of high frequency current modified in the proper manner are inserted directly in series with the line circuit, whereas in the co-pending application these sources of high frequency currents are bridged across the line.

In the drawings forming a part of this specification several modifications for the circuit connections are shown, and in said drawings, Figure 1 illustrates a form of circuit in which a single high frequency oscillatory telephonic message is impressed upon the line by a series connection. Fig. 2 shows a modification of Fig. 1 and contains a plurality of transmitters and receivers connected to the line. Fig. 3 illustrates still a further modification.

Referring to these figures in detail Fig. 1 shows a common metallic circuit for ordinary telephony, across which is bridged the ordinary telephone sets B and B′. These telephone sets include the usual apparatus as in present use in local battery telephone circuits, there being shown a microphone transmitter 1 with its local battery 2 and the primary of the transformer 3. Also there is shown connected in the usual way the ringing circuit 4 and the switchhook 5 with the receiver 6. The secondary of the transformer 3 is bridged directly across the line wires A and A′ when the receiver is off the hook. The invention is not in any way connected with the details of this telephone connection, any of the usual circuit connections being suitable and the one described being given merely as an illustration. In series with the telephone sets B and B′ and connected directly in the line circuit is the secondary S of the transformer 9, the primary P of which transformer is contained in a circuit including the high frequency generator G, the microphone M, the variable condenser C and the variable inductance L. At another point of the line, which represents the receiving station, is placed the primary P′ of a transformer 10, this primary being directly in series with the battery sets in the same manner precisely as the secondary S of the transformer 9. The secondary S′ of the transformer 10 is connected in series with a variable inductance L′ and a variable condenser C′. In shunt to the condenser C′ is placed a detector D of any suitable type, such as, for instance, the audion. In operative connection to the detector D is the telephone head-piece F. Bridged across the line as shown are the two variable condensers K and K′. These condensers are of such small capacity as to interpose very high impedance to the ordinary telephonic currrents set up by the telephone sets B, but, being of dimensions of some thousandths of a microfarad, interpose practically no impedance to the high frequency currents developed by the generator G.

The operation of this system is as follows: Currents set up in the usual way by the telephone transmitter set B will be transmitted over the line to the receiving station placed at any desired and convenient point. High frequency currents developed by the generator G and modified by the microphone M are also impressed upon the line simultaneously therewith. Although these currents exist on the line at the same time, they exert no influence upon each other whatsoever, and the ordinary telephonic messages pass through the primary P′ of the transformer 10 without in any way operatively affecting the tuned circuit L′ C′, this circuit being tuned to the frequency of the oscillations developed by the generator G. The high frequency currents, however, are unable to affect the transmitter B, being of ultra-sound frequency, and furthermore are practically, if not totally, unable to pass through this set because of its high impedance. The high frequency oscillations set up in the circuit L′ C′, retaining the modifications impressed upon it by the microphone M, are then transformed by the detector D, giving a reproduction of speech in the telephone F. As shown in this figure, the local generator circuit may be tuned to the frequency of the generator G by means of the condenser C and the inductance L, and this is particularly desirable where the power of the generator is limited. This also affords a convenient method of diminishing the output of the generator, this being accomplished by throwing the circuits slightly out of tune. The transformers 9 and 10 are also made in such a manner as to give a variable coupling, this being most readily accomplished by making one coil slide within the other or one coil swing within the other, although any other well known method may be used.

The generator circuit may be modified in various ways without in any way affecting the principle of the invention. The same is true also of the receiver circuit. Various modifications for both the generator circuit and the receiver circuit are given in my co-pending application, Serial Number 590;801 cited above. It is to be understood that any of the circuits there shown may be substituted for the ones herein. If desired, choke coils E may be placed in series with the telephone circuit to give this a higher impedance for the high frequency circuits. In practice, however, this has not been found to be necessary.

Fig. 2 shows a circuit in which a plurality of transmitter and receiver circuits are connected in series in the line, the action of each one being similar precisely to that described in connection with Fig. 1. The transmitters and receivers have been indicated diagrammatically only and are indicated by the reference characters T and R, it being understood that any suitable form of generator circuit or receiver circuit, such as shown in Fig. 1, or in my co-pending application Serial Number 590,801 being useful in this relation. The telephone battery sets B and B′ are indicated diagrammatically only, but it is to be understood that such connections as are shown in Fig. 1 should be used. In practice it would be desirable, of course, to have an equal number of transmitters and receivers at each end of the line, and for each transmitter circuit there will be a receiver circuit tuned to the same frequency.

Fig. 3 shows still a further modification, which is a combination of series connected high frequency circuits on Figs. 1 and 2, with the bridge connections shown in my co-pending application, Serial Number 590,801 mentioned above. In this figure there are shown connected in series relation the two transmitters T and the receivers R, and connected across in bridge to the line are shown two transmitters T′ and two receivers R′. In these bridge connections there are shown variable inductances L_1 in series with variable condensers C_1 and transformer coils H. These bridge connections are the same whether used in connection with a transmitter circuit or a receiver circuit. A typical form of transmitter circuit is shown at T′ where G′ indicates the high frequency generator in series with a variable inductance L″, variable capacity C″ and signaling instrument K″. This circuit is then inductively connected to the bridging circuit by the transformer H. The receiver circuit shown at R′ is similar in every respect to the receiver circuit shown in Fig. 1, being tuned to the frequency of the transmitter with which it is to communicate. By means of the variable inductance and variable capacity in the bridging circuits, it is possible to tune a pair of these with the line to the frequency of the oscillations to be used, and, of course, a different period or frequency will preferably be used for each and every transmitting circuit, whether it be connected in bridge or in series with the line. It is apparent from the above that by the arrangement of this Fig. 3 I am enabled to transmit simultaneously a large number of telephonic messages and obtain thereby an efficient and useful multiplex telephone system, the whole being attained by impressing high frequency currents upon the usual metallic circuit for local telephone sets without in any way affecting the transmission or reception of these ordinary telephone circuits.

Although I have described my invention as being adapted for telephonic work, it is obvious that the same may be used for telegraphic work. This is indicated in Fig. 3, where a signaling instrument is shown as an ordinary telegraphic key. In many cases it is not desirable to completely break the circuit of the generator G′, and in this case various expedients may be used, such, for instance, as shown and described in Fig. 3 of my co-pending application, Serial Number 590,801. In Fig. 3 it is not necessary to use the condensers K and K′ shown in Figs. 1 and 2, for the bridging circuits afford paths of low impedance for the oscillations developed by the series connected generators and the condensers C_1 prevent short circuiting of the sets B and B′.

It is obvious that the telephone sets B and B′ may be dispensed with, in which case all the communication will be carried on by high frequency currents, still making multiplex telephony possible. In this case, the Figs. 1 and 2 may be modified by eliminating the condensers K and K′ and short circuiting the line wires at the extreme ends.

Although several modifications have been described in detail in this specification, it is obvious that many changes may be made without departing from the spirit of the invention, and I therefore do not wish to be limited to the exact connections shown, but

What I claim as my invention is the following:

1. In a multiplex telephone and telegraph system, the combination of a pair of line wires, battery telephone sets bridged across said wires, a high frequency generator connected in series in said line; a receiver for high frequency oscillations connected in series in said line as and for the purpose described.

2. In a multiplex telephone and telegraph system, the combination of a pair of line wires, battery telephone sets bridged across said wires; a source of high frequency electric waves connected inductively in series relation in said line, means for modifying said electric waves; a receiver tuned to said high frequency electric waves and connected in series relation in said line.

3. In a multiplex telephone and telegraph system, the combination of a pair of line wires, battery telephone sets bridged across said wires, a source of electric waves of ultra-sound frequency connected in series relation in said line, a signaling instrument for modifying said oscillations, a receiver tuned to said source of high frequency electric waves and connected in series relation in said line, a detector for electric waves in said receiver circuit and a telephone operatively connected to said detector.

4. In a multiplex telephone and telegraph system, the combination of a pair of line wires, a plurality of sources of high frequency oscillations connected in series relation in said line, a signaling instrument for each source of high frequency oscillations for modifying said oscillations; a plurality of receiver circuits, each tuned to the frequency of one source of high frequency oscillations and connected in series relation in the line, an integrating detector in each receiver circuit and a telephone operatively connected to each detector.

5. In a multiplex telephone and telegraph system, the combination of a pair of line wires, a condenser of small capacity bridged across each end thereof, battery telephone sets bridged across said wires, a high frequency dynamo in series with a variable condenser, a variable inductance, a telephone transmitter and the primary of a transformer the secondary of said transformer being in series in the line, a receiver circuit comprising a variable condenser, a variable inductance and the secondary of a transformer, the primary of said transformer being connected in series in the line; an integrating detector in shunt to the condenser and a telephone operatively connected thereto.

6. In a multiplex telephone system, the combination of a pair of line wires, a variable condenser of small capacity bridged across each end of said line wires, battery telephone sets bridged across said line wires, a plurality of transmitter circuits, each consisting of a high frequency dynamo with a circuit adapted to be tuned, each circuit including a microphone transmitter for modifying the oscillations and the primary of a transformer, the secondaries being connected in series in said line, a plurality of receiver

circuits, one for each transmitter circuit, containing a condenser, an inductance for turning the same to its transmitter circuit and the secondary of the transformer, the primary of said transformer being in series in the line, an audion detector in shunt to the condenser and a telephone operatively connected to the audion.

7. In a multiplex telephone and telegraph system, the combination of a pair of line wires, battery telephone sets bridged across said line wires, a plurality of transmitter circuits, each consisting of a high frequency generator with a circuit adapted to be tuned, each circuit including a signaling instrument for modifying the oscillations and the primary of a transformer, the secondaries being connected in series in said line, a plurality of similar transmitter circuits, the secondaries of the transformers being connected in circuits bridged across said lines, said bridges including a variable capacity and inductance for tuning; a plurality of receiver circuits, one for each transmitter circuit, containing a condenser, and an inductance for tuning the same to its transmitter circuit and the secondary of a transformer; the primaries of a portion of said transformers being in series with the line, and the primaries of the others being in circuits bridged across the line, each bridge circuit being similar to the transmitter bridge circuits, a vacuum detector in shunt to the condenser in each receiver circuit and a telephone operatively connected to the detector.

8. In a multiplex telephone and telegraph system, the combination of a pair of line wires, a plurality of transmitter circuits, each consisting of a high frequency generator with a circuit adapted to be tuned, each circuit including a signaling instrument for modifying the oscillations and the primary of a transformer, the secondaries being connected in series in said line, a plurality of similar transmitter circuits, the secondaries of the transformers being connected in circuits bridged across said line, said bridges including a variable capacity and inductance for tuning, a plurality of receiver circuits, one for each transmitter circuit, containing a condenser, and an inductance for tuning the same to its transmitter circuit and the secondary of a transformer, the primaries of a portion of said transformers being in series with the line, and the primaries of the others being in circuits bridged across the line, each bridge circuit being similar to the transmitter bridge circuits; a vacuum detector in shunt to the condenser in each receiver and a telephone operatively connected to the detector.

GEORGE OWEN SQUIER.

Witnesses:

P. I. WOLD,

E. R. CRAM.

UNITED STATES PATENT OFFICE.

GEORGE OWEN SQUIER, OF THE UNITED STATES ARMY.

MULTIPLEX TELEPHONY AND TELEGRAPHY.

980,358. Specification of Letters Patent. **Patented Jan. 3, 1911.**

Application filed November 5, 1910. Serial No. 590,803.

(Dedicated to the public.)

To all whom it may concern:

Be it known that I, George Owen Squier, major in the Signal Corps, U. S. Army, a citizen of the United States, and residing at Washington, District of Columbia, (whose post-office address is War Department, Washington, District of Columbia), have invented certain new and useful Improvements in Multiplex Telephony and Telegraphy, of which the following is a specification.

This application is made under the act of March 3, 1883, chapter 143, U. S. Statute XXII, p. 625, and the invention herein described and claimed may be used by the Government of the United States or any of its officers or employees in the prosecution of work for the United States or by any person in the United States without the payment of any royalty thereon.

This invention relates to multiplex telephony and telegraphy and has as its object the simultaneous transmission of a plurality of telephonic and telegraphic messages over a single circuit.

A further object of the invention is to make use of a grounded, or earthed, circuit for multiplex telephony in such a manner as to avoid the disturbances arising from such causes as give trouble in the ordinary grounded telephone circuit.

A further object is to apply electric waves of such different frequencies as to make possible the selection and complete independence of the various messages.

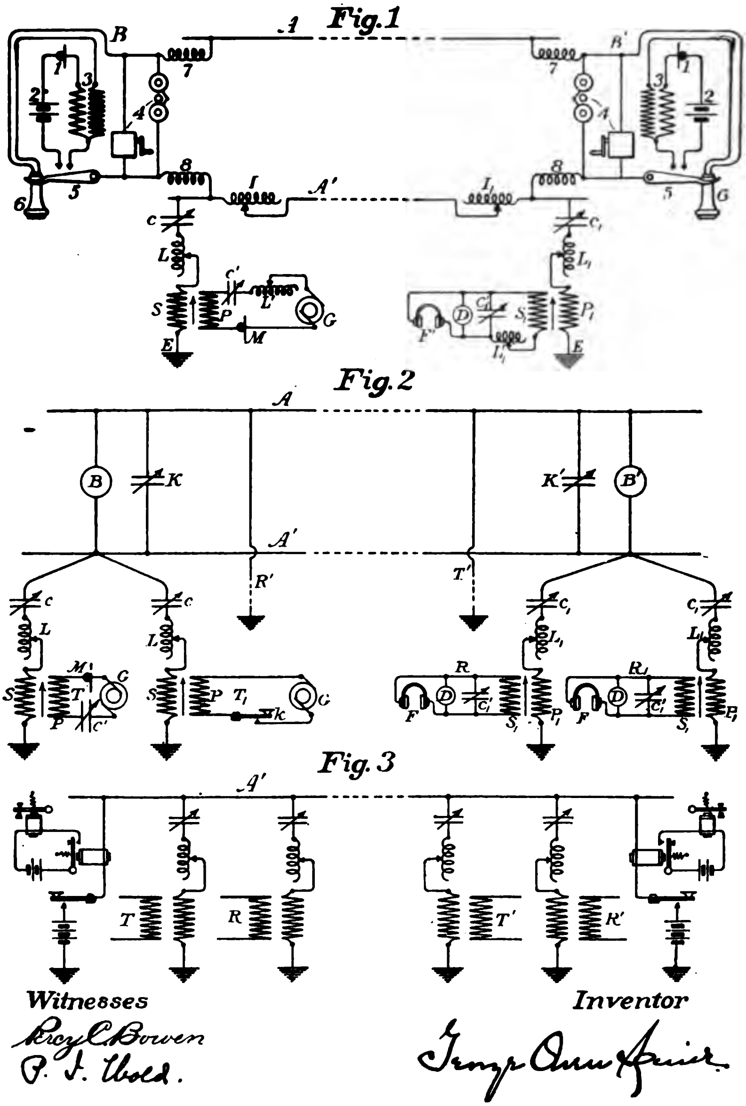
A further object is to superimpose upon a standard battery telephone circuit, as now commercially used, one or more telephonic and telegraphic circuits without any interference of the various messages.

In accomplishing the above results, use is made of electro-magnetic waves, or oscillations, of high frequency, guided by wires.

Reference is here made to my co-pending applications, Serial Nos. 590,801 and 590,802, filed November 5, 1910, in which applications I have discussed at length the advantages and limitations of high frequency electric waves, or oscillations, for the transmission of intelligence. As in these above mentioned applications, I ordinarily make use of frequencies above the limit of audibility, which may be taken as ranging from about 15,000 cycles per second up, and accordingly, in this application, when reference is made to high frequency oscillations, it is understood to mean oscillations of ultra-sound frequencies or a frequency above human audition.

G. O. SQUIER.
MULTIPLEX TELEPHONY AND TELEGRAPHY.
APPLICATION FILED NOV. 5, 1910.

980,358. Patented Jan. 3, 1911.



Witnesses

Inventor

It has been found necessary in order to obtain efficient results to make use of such detectors as are commonly found in the wireless telegraphic art. Attempts have been made at multiplex telephony, but I have found these inoperative, for the reason, among others, that no detector, or equivalent device, has been used. These detectors are not used because of any greater inherent sensitiveness to electric energy than resides in the telephone receiver itself, but because the energy, being in the form of rapid oscillations, cannot affect a telephone or other indicating device. These rapid oscillations cannot sensibly affect the telephone, because the diaphragm in its motion reverses with the reversal of the current, and the deflecting impulse, if applied directly to the telephone receiver, will be first in one direction and then in the other, with a frequency so high that the diaphragm cannot follow or respond. Furthermore, if the diaphragm should respond with this frequency, the effect would not be audible. Also, in the case of the ordinary telephone, on account of the large self-inductance of the instrument, the high frequency E. M. F. generated by the waves would produce in a telephone receiver only extremely weak currents. I have found it necessary, therefore, and consider it an important part of this invention, to make use of some form of integrating detector to transform these rapid oscillation into effects which can be manifested by the indicating instruments.

In practice, I have made use of a pair of telephone lines in the common and ordinary telephone cables, such as is used in city telephone traffic, the pair in use being but one of a large number of paper-covered twisted-pairs inclosed in a lead sheath, the cable being placed principally underground. The electric waves or oscillations pass along this conductor in the manner originally investigated by Hertz and as now understood in connection with the transmission of electric waves along metallic wires.

The invention described in this application is similar to that described in my co-pending applications, Serial Numbers 590,801 and 590,802, filed November 5, 1910, but differs from these in that the high frequency oscillatory circuits are suitably connected to ground or earth.

In the drawings forming a part of this specification, several modifications of the circuit connections are shown, and in said drawings, Figure 1 illustrates a form of circuit in which a high frequency transmitter and receiver are connected to the line and to the earth. Fig. 2 shows a modification of this circuit in which a plurality of high frequency transmitters is used. Fig. 3 shows still another modification.

Referring to these figures in detail, Fig. 1 shows a common metallic circuit for ordinary telephony in which local batteries are used at each station. In this figure, A and A′ represent a pair of conductors twisted together and placed within a lead sheath, being but one out of a plurality of pairs in said sheath. Across these line wires are bridged the local telephone sets B and B′, each set being precisely similar and comprising a microphone transmitter 1, in series with a battery 2, and the primary of a transformer 3. The ringing circuit is shown at 4 and the switch hook with its contact points at 5, the receiver at 6. The telephone set as described includes merely the ordinary apparatus used in a local telephone set. The invention is not in any way connected with the details of this telephone connection, any other of the usual circuit connections being suitable, and the one described being given merely as an illustration. If desired, the choke coils 7 and 8 may be used with the telephone sets as shown, to prevent the passage of high frequency oscillations through them, but in practice I have found this unnecessary, for the telephone sets interpose sufficient impedance in themselves to prevent the passage of high frequency currents. Connected to the line at or near one of the terminals of the telephone set B is a circuit connected to the earth E, this circuit including a variable condenser C, a variable inductance L, and the secondary S of the transformer. Inductively connected to the secondary S is the primary P of the transformer, to which is connected the high frequency generator G, and, in circuit with these, are shown the variable capacity C′, the variable inductance L′ and the microphone M. At or near the station B′ is connected a similar circuit containing the variable condenser C_1, the variable inductance L_1, and the primary P_1 of a transformer, the earth connection being shown at E. The secondary S_1 of the transformer forms part of the oscillatory circuit containing the variable capacity C_1' and the variable inductance L_1'. In shunt to the capacity C_1' is the detector D, which may be of any suitable form such as the audion or the perikon. I have found the audion particularly useful in this relation, because of the small attention required in adjustments. Operatively associated with the detector D is the telephone receiver F. The condensers C and C_1 and inductances L and L_1 serve for the purpose of tuning the line with the earth connections to the frequency of the generator G. If desired, additional inductances I and I_1 may be inserted in the line to help further in the tuning.

The operation of the device is as follows: The high frequency oscillations generated by G are impressed on the circuit C—L—S, which then travel out on the line A′, these oscillations being modified in accordance with speech by the microphone M. The oscillations are selected and absorbed by the oscillatory circuit C_1' L_1' S_1 which is tuned to the frequency of the oscillations received. These oscillations are then transformed or rectified by the detector D, and the speech is reproduced in the telephone F in the manner well understood in the art of wireless telephony. The condenser C′ and the inductance L′ are used for tuning the generator circuit to the frequency of the generator. This is particularly useful where the power of the generator is limited, but these elements are also useful in regulating the amount of energy supplied by the generator G, for, by throwing the circuits slightly out of tune, the energy transmitted may be materially reduced. An important feature of these connections lies in the condensers C and C_1, for these condensers, in addition to serving as tuning elements, isolate the line A—A′ from the earth so far as ordinary telephonic currents are concerned.

As is well known, it has been impossible to obtain satisfactory battery telephony over any circuit which is connected to ground in any way whatsoever, except in some few cases of elaborate and delicate balancing of circuits to prevent interference, and then only to a limited extent. Lines constructed with ground circuits are found to be subject to serious difficulties, chief among which are the strange noises heard in the receiving instruments. The exact causes of these noises are not entirely understood, but they are of sufficient effect to make a grounded telephone circuit exceedingly noisy and undesirable. In the present invention, however, I am able to connect a telephone circuit to earth at both ends without perceiving the slightest trace of any disturbing noises, and I consider this accomplishment of a silent earth connection an important feature of my invention. In actual practice I find that the high frequency telephonic messages and the local battery telephonic messages may exist on the line simultaneously without a trace whatsoever of any cross-talk or disturbing noises from other external sources. I consider that this is made possible by the fact that the condensers C and C_1 are of a very small capacity, being measured in terms of thousandths of a microfarad and, as such, interpose an extremely high impedance to all currents of such low frequencies as the ordinary telephonic currents or disturbing currents from external sources. Furthermore, since these earth or ground connections form a part of tuned circuits including the line, no disturbances from the earth are permitted to pass, since all such earth connections are tuned to frequencies entirely above audition. The result I obtain would be entirely impossible if condensers and inductances of such size as are now commonly used in telephonic practice were inserted in the circuit, for such condensers and inductances are very large indeed compared to the ones I actually use. In some cases, the condenser C on the transmitter end may be omitted, but, in general, results are more satisfactory with both condensers C and C_1 in circuit.

The high frequency oscillation transformers are so constructed as to give a variable coupling in any suitable manner, such, for instance, as sliding the coils S and S_1 into or out of the primaries P and P_1 or swinging one within the other. Obviously any other suitable method for obtaining variable coupling may be used.

Fig. 2 shows a form of circuit in which a plurality of high frequency generators of different frequencies is used to impress energy upon the line circuit A—A^4. The connection of the local battery sets across the lines is precisely the same as in Fig. 1 and is here shown only diagrammatically at B—B′. Connected at or near the terminal B is a plurality of circuits containing a condenser C, an inductance L, and the secondary of a transformer, connection being made to earth at E. These circuits are precisely the same as were described in connection with Fig. 1. To each circuit there is inductively connected a transmitter circuit containing a generator with tuning elements and a suitable signaling instrument. In the circuit T_1, I have shown the microphone transmitter replaced by a telegraphic key K, which telegraphic key may be connected into the circuit in a variety of ways, such, for instance, as shown in this Fig. 2, or as shown in Fig. 3 of my co-pending application, Serial Number 590,801, cited above. At the station B′, I have shown a plurality of circuits connected to ground, these circuits containing a condenser C_1 and inductance L_4, and the primary of a transformer in the manner described in connection with Fig. 1. To each of these circuits, there is inductively connected a receiving circuit similar in every respect to the receiver circuit shown and described in connection with Fig. 1. These receiver circuits are tuned to different frequencies, each being tuned to the frequency of one of the transmitters at the other end of the line. In view of this difference in frequency, it is obvious that oscillations sent from the transmitter T will be selected by the receiver R, and oscillations sent by the transmitter T_1 will be selected and received by the receiver R_1, thus giving multiplex telephony or telegraphy by high frequency currents in addition to the ordinary local battery telephone currents. In shunt to the line may be placed condensers K and K′ in order to connect the two lines A and A′ in parallel for the high frequency currents. These condensers, however, are of such small dimensions as to interpose a practically insuperable impedance to the currents from the telephone sets B and B′. In practice it is not necessary to use the condensers K and K′. Obviously, any number of high frequency circuits of different periods may be connected to the line circuits, some being connected to the wire A′ and some to the wire A, as shown at R′ and T′. Obviously, also, it will be desirable in practice to have an equal number of receiver and transmitter stations at each end of the line, in order that communication may be carried on in both directions. In this figure, as in Fig. 1, I have shown a local battery telephone circuit grounded at each end, and this is done without in any way affecting the working of the local telephone sets, so that I attain a silent grounded telephone circuit.

Fig. 3 shows a modification in which one line wire A and the telephone sets B and B′ have been entirely eliminated. In this case, a plurality of high frequency transmitters and receivers is connected to the line as shown, the transmitters being shown diagrammatically at T and T′ and the receivers at R and R′. Each of these transmitter and receiver stations is similar to those described in connection with Figs. 1 and 2. There may, of course, be a larger number of these circuits connected than is shown, and each transmitter may be tuned to a different frequency and one receiver will be tuned to each transmitter. In this modification, as is apparent, I have attained with a single grounded wire, a telephone circuit which is entirely silent so far as disturbing impulses are concerned, and as I stated previously, I consider this an important feature of my invention. In addition to obtaining a silent grounded one-wire telephone circuit, I have in this figure shown multiplex telephony.

In Figs. 1 and 2, I have shown specific forms of transmitter and receiver circuits, but it is obvious that each of these circuits may be modified in various ways without in any way affecting my invention. Modifications of these circuits are shown in my co-pending application, Serial Number 590,801, and it is to be understood that any of the forms of circuits shown therein may be substituted for the circuits shown herein.

The standard telegraph circuit of the world employs the earth as the return conductor, and in Fig. 3 is shown such a standard telegraph circuit comprising the regular Morse equipment for a single line with stations at each end. Upon this standard Morse telegraph line are superimposed the high frequency telegraph circuits as indicated in said Fig. 3. I have not shown other circuit drawings for the superposition of high frequency telegraph circuits upon other standard types of telegraph circuits as now practiced, such as the regular Morse "way line," the differential duplex, the polar duplex, the duplex-diplex, etc., but it is manifest that such superposition is readily operative and practical by the identical methods and forms of apparatus already fully described in this specification and also in my co-pending applications, Serial Numbers 590,801 and 590,802. In general, by shunting the present Morse way station apparatus or the terminal apparatus by a suitable low-valued variable condenser, or condenser and inductance tuned with the line circuit to the high frequency of the generator, the complete separation of the two messages is effected. I have not, therefore, considered it necessary to multiply drawings in this specification to indicate how this is accomplished in each case, but I wish it understood that this invention comprises and includes the methods as above described for superimposing upon the ordinary manual Morse telegraph circuits, employing keys, relays and sounders, high frequency telegraphic circuits, in the manner and by the means substantially as described.

Although several modifications have been described in detail in this specification, it is apparent that many other changes may be made without departing from the spirit of the invention, and I therefore do not wish to be limited to the exact connections shown, but

What I claim as my invention is the following:

1. In a multiplex signaling system a line wire, low frequency signaling instruments connected to said line wire; a circuit for high frequency currents comprising the line and silent earth connections; means for impressing high frequency oscillations, modified in accordance with signals on said high frequency circuit, a receiver circuit including a detector for electric waves associated with said high frequency circuit and a translating device operatively connected to the detector.

2. In a multiplex signaling system a line wire, low frequency signaling instruments connected to said line wire, a plurality of earth connections bridged from line to earth, means for impressing high frequency oscillations of different frequencies on each bridged connection, means for modifying said oscillations; a plurality of similar earth connections bridged from line to earth; a plurality of receiving circuits, one connected to each of the second named earth connections, a detector for high frequency oscillations in each receiver circuit and a telephone operatively connected to the detector, each pair of corresponding bridge connections with the line wire being tuned to the frequency of the oscillations impressed thereon.

3. In a multiplex telephone and telegraph system, a pair of line wires, battery telephone sets bridged across said line wires; silent earth connections including a variable condenser and a variable inductance, means for generating electric waves of ultra-sound frequencies connected to one of said earth connections, means for modifying said electric waves; a receiver circuit connected to another similar earth connection, a detector for ultra-sound electric waves in said receiver circuit and a telephone operatively connected to the detector.

4. In a multiplex telephone and telegraph system, a pair of line wires, battery telephone sets bridged across said line wires; silent earth connections, including a variable condenser and a variable inductance; a dynamo for generating high frequency electric waves connected inductively to one of said earth connections, a telephone transmitter for modifying said electric waves; a receiver circuit connected to another similar earth connection, a detector for high frequency electric waves in said receiver circuit, and a telephone operatively connected to the detector, said

receiver circuit and the earth connections with the line being tuned to the frequency of the generator.

5. In a multiplex telephone system, a pair of line wires, battery telephone sets bridged across said line wires; a plurality of silent earth connections, including variable condensers and variable inductances; a plurality of generators of high frequency electric waves of different ultra-sound frequencies, one connected inductively to each earth connection; microphone transmitters for each generator for modifying said electric waves; a plurality of earth connections similar to the transmitter earth connections; a plurality of receiver circuits, one connected to each of the second named earth connections, an integrating detector for high frequency electric waves in each receiver circuit, and a telephone operatively connected to the detector.

6. In a multiplex telephone system, a pair of line wires, a condenser of small capacity bridged across said lines, a plurality of earth connections, including variable condensers and variable inductances; a plurality of generators of high frequency electric waves of different ultra-sound frequencies, one connected inductively to each earth connection; microphone transmitters for each generator for modifying said electric waves; a plurality of earth connections similar to the transmitter earth connections; a plurality of receiver circuits, one connected to each of the second named earth connections, an integrating detector for high frequency electric waves in each receiver circuit and a telephone operatively connected to the detector.

7. In a multiplex telephone system, a pair of line wires, battery telephone sets bridged across said line wires, a condenser of small capacity connected in parallel to said telephone sets; a plurality of earth connections, including a variable condenser and a variable inductance, connected from each line wire to earth; a plurality of transmitter circuits inductively connected to said earth connections, each transmitter circuit including a high frequency generator, a variable capacity, a variable inductance and a microphone transmitter; a plurality of similar earth connections; a plurality of receiver circuits, one inductively connected to each of the second named earth connections, each receiver circuit including a variable inductance and a variable capacity, a detector shunted around said condenser and a telephone operatively connected to said detector, each receiver circuit and the corresponding pair of bridge circuits with line being tuned to the frequency of its corresponding generator.

George Owen Squier.

Witnesses:

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UNITED STATES PATENT OFFICE.

GEORGE OWEN SQUIER, OF THE UNITED STATES ARMY.

MULTIPLEX TELEPHONY AND TELEGRAPHY.

980,359. Specification of Letters Patent. **Patented Jan. 3, 1911.**

Application filed November 5, 1910. Serial No. 590,804.

(Dedicated to the public.)

To all whom it may concern:

Be it known that I, George Owen Squier, major in the Signal Corps, U. S. Army, a citizen of the United States, and residing at Washington, District of Columbia, (whose post-office address is War Department, Washington, District of Columbia,) have invented certain new and useful Improvements in Multiplex Telephony and Telegraphy, of which the following is a specification.

This application is made under the act of March 3, 1883, chapter 143, (U. S. Statute XXII, p. 625,) and the invention herein described and claimed may be used by the Government of the United States or any of its officers or employees in the prosecution of work for the United States or by any person in the United States without the payment of any royalty thereon.

This invention relates to multiplex telephony and telegraphy and has as its object the simultaneous transmission of a plurality of telephonic and telegraphic messages over a single circuit.

A further object of the invention is to make use of grounded or earthed connections in combination with the usual metallic circuit.

A further object is to render such a system as the above silent to external disturbances and in such manner as to eliminate all cross-talk or harmful effects of one message upon another.

A further object is to apply electric waves of such frequencies as to make possible the selection and complete independence of the various messages.

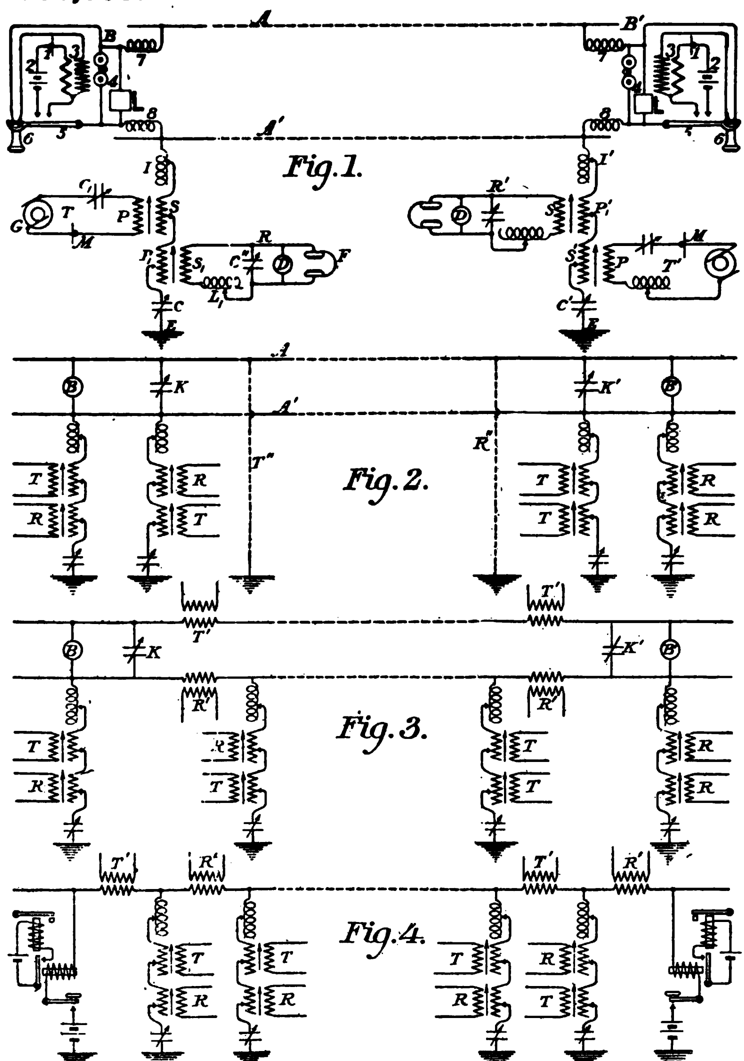
A further object is to superimpose upon a standard battery telephone circuit, as now commercially in use, one or more telephonic and telegraphic circuits without any interference of the various messages.

In accomplishing the above results, use is made of electromagnetic waves, or oscillations, of high frequency, propagated by means of wires, and where use is made in this application of the term high frequency, it is understood to mean any ultra-sound frequency or frequencies above the limit of audition.

Reference is here made to my co-pending applications, Serial Numbers 590,801 and 590,802, filed November 5, 1910, in which I have discussed at length the advantages and limitations of the use of electromagnetic waves of various frequencies in such systems as described there and here. In accomplishing the desired results, I have found it necessary and sufficient to combine the engineering practice of wireless telegraphy and telephony with the engineering practice of wire telegraphy and telephony. I have also found it necessary, in order to obtain satisfactory results, to make use

G. O. SQUIER.
MULTIPLEX TELEPHONY AND TELEGRAPHY.
APPLICATION FILED NOV. 8, 1910.

980,359. Patented Jan. 3, 1911.



Witnesses:

Inventor:

George Owen Squier

of such detectors as are commonly found in the wireless telegraphic art. Attempts have been made at multiplex telephony, but I have found these inoperative for the reason, among others, that no detector or equivalent device has been used. These detectors are not used because of any greater inherent sensitiveness to electrical energy than resides in the telephone receiver itself, but because the energy being in the form of rapid oscillations cannot affect the telephone or rather communicating device. These rapid oscillations cannot sensibly affect the telephone, because the diaphragm in its motion must reverse with the reversal of the current and the deflecting impulse if applied directly to the telephone receiver will be first in one direction and then in the other with a frequency so high that the diaphragm cannot sensibly follow or respond. Furthermore, if the diaphragm should respond with this frequency the effect would not be audible. Also in the case of the ordinary telephone, on account of the large self-inductance of the instrument, the high frequency E. M. F. generated by the waves would produce in the telephone receiver only extremely weak currents. I have found it necessary therefore, and consider it an important part of my invention, to make use of some form of integrating detector to transform the rapid oscillations into effects which can be manifested by the indicating instrument.

This application is closely related to my three co-pending applications, Serial Numbers 590,801, 590,802, and 590,803, filed November 5, 1910. In each of these, use is made of high frequency waves as a vehicle for the telephone or telegraph messages which are impressed upon the same line as carries the telephonic currents from an ordinary local battery telephone set.

In my co-pending application, Serial Number 590,803, I have shown a specific manner of connecting a plurality of high frequency circuits in parallel between the ordinary battery line and the earth. In this application I shall describe a manner of connecting a plurality of such high frequency circuits in series relation, making use of the telephone circuit and ground connections.

In the drawings forming a part of this specification, several modifications for circuit connections are shown, and in said drawings, Figure 1 illustrates a circuit in which a plurality of transmitting or receiving circuits is connected in series in a circuit between the earth and the ordinary telephone line. Figs. 2, 3 and 4 illustrate a modification of Fig. 1.

Referring to these figures in detail, Fig. 1 shows a common metallic circuit A—A′ for ordinary telephony, across which are bridged the telephone sets B B′. These telephone sets include the usual apparatus in present use in local battery circuits, there being shown a transmitter 1 of any suitable form such as a microphone transmitter with its local battery 2 and the primary of the transformer 3. Also there are shown connected in the usual way the ringing circuit 4, the switchhook 5 and the receiver 6. The secondary of the transformer 3 is bridged directly across the line when the receiver is off the hook. The invention is not in any way connected with the details of this telephone connection, any of the usual circuits being suitable, and the one described being given merely as an illustration. Connected to the line wire A′, at or near its connection to the telephone set B, I have shown a circuit connection to the earth at E, this circuit including the variable inductance I, the secondary coil S, the primary coil P_1 and the variable condenser C, these all being connected directly in series. Inductively connected to the secondary S is a primary coil P which is in circuit with the high frequency generator G, this circuit also including a variable condenser C_1 and a microphone M. Inductively connected to the primary P_1 is a secondary coil S_1, including in its circuit a variable condenser C″ and a variable inductance L′. Shunted around the condenser is the detector D, and operatively associated with the detector D is the telephone set F, with a battery if desired. At or near the station B′ is a similar earth connection, including the inductance I′, the primary P_1', the secondary S′ and the condenser C′, these being all variable and connected in series in the same manner as shown at the station B. Inductively connected to the primary P_1' is a receiver circuit R′, similar in every respect to the receiver R at the station B. Inductively connected to the secondary S′ is a transmitter circuit T′, similar in every respect to the transmitter circuit T at the station B. The receiver R′ is tuned to the frequency of the oscillations given off by the transmitter T and the receiver circuit R is tuned to the frequency developed by the transmitter T′, these frequencies being sufficiently different to afford effective, selective tuning. The tuning elements throughout the circuit which comprise the various condensers and inductances are all variable in order to permit of ready and effective tuning of each and any circuit. The high frequency transformers are all so constructed as to give variable coupling, either by sliding the one coil within the other, or having one coil swing within the other, or by any other suitable method well known in the wireless art.

The operation of the system is as follows: Ordinary telephonic communications may be carried on between the stations B and B′ by the telephone sets. Simultaneously therewith high frequency oscillations may be impressed on the line A′ by the transmitter circuits T and T′; both of these operating at the same time, if desired. These high frequency oscillations are modified in accordance with speech by the microphone M, and oscillations transmitted by T are picked up by the receiver R′ and are rectified or transformed by the detector D in such a way as to give a reproduction of speech in the telephone F, all of these being well known in the art. So also oscillations modified by the microphone M at the transmitter circuit T′ will be translated into speech at the station R. All of these messages may exist on the same line at the same time without any cross-talk or interference whatsoever. If desired, one or more of the microphones M may be replaced by suitable telegraphic keys in order that communication by telegraphy may be carried on. Obviously this change will not affect the principle of the operation in any way whatsoever. The telegraphic signals may be produced by the ordinary key placed directly in the generator circuit or by such an arrangement as is shown in Fig. 3 of my co-pending application, Serial Number 590,801. It is to be noted in this circuit that I have connected a metallic circuit to earth at both ends, and I have done this without experiencing any difficulty in consequence of external disturbances. I am able to accomplish this by means of the condensers G and C′, which, in addition to acting as tuning elements, also act as a check to any earth disturbances in the vicinity. This is possible only because the condensers C and C′ here used are of very small electrical dimensions, being measured in some thousandths of a microfarad, whereas the condensers now in ordinary use in telephone practice have a capacity measured in microfarads. Such large condensers offer very small impedance to the passage of external disturbances of such frequencies as are within the audible limit, but with my very small condensers and sharp tuning in the ground circuit to a frequency entirely above audition, these low frequency audible disturbances are entirely shut out, giving me what I choose to call a "silent ground connection". In view of the fact that heretofore single line telephone circuits which include a ground return, or a 2-wire telephone circuit which is grounded at either end, are subject to many and strange noises, the causes of which are not entirely understood, I consider that my present invention, whereby I am enabled to use a ground connection on a single telephone circuit with no such disturbances, a very important and essential part of my invention. I have found the above circuits entirely successful on a standard telephone line circuit consisting of a pair of twisted copper conductors, paper insulated, which pair constitutes but one out of a large number inclosed in a lead sheath used in ordinary city traffic. This lead sheath surrounding the pair of wires brings the earth connection very close indeed to the line circuit all along its length, but in spite of this, my selective circuits are so effective as to give no trace whatsoever of any cross-talk or influence due to external disturbances. It is apparent that any number of transmitter or receiver circuits may be connected in series in addition to the two shown in Fig. 1.

Fig. 2 shows a modification of Fig. 1, in which a plurality of earth branches are connected in parallel, each single branch connected to earth being similar in every respect to the earth branches shown in Fig. 1, and each including two or more circuits which may be transmitter or receiver circuits, these circuits being indicated only diagrammatically and designated by the reference characters T and R throughout. The connections of the battery sets B and B′ are shown only diagrammatically, it being understood that the connections are similar to those shown in Fig. 1. Each transmitter has a different frequency always being of ultra-sound frequency, and each transmitter has a corresponding receiver circuit at the other end of the line tuned to its frequency. I may also use condensers K and K′ bridged across the lines A A′ which serve the purpose of placing the two lines A and A′ in parallel for the high frequency currents. This capacity, however, is made so small as to give practically insuperable impedance to the telephone currents of ordinary frequencies as given by the telephone sets B and B′. It is also obvious, as shown in Fig. 2, that high frequency currents may be connected to the line wire A as shown at T″ and R″, these circuits having connected in them a plurality of transmitter or receiver circuits in any suitable arrangement.

Fig. 3 shows a further modification, which is a combination of the systems shown in Figs. 1 and 2 and the systems shown in my co-pending application, Serial Number 590,802. In this figure, a plurality of branches connected to the earth is shown, each circuit including a plurality of transmitter or receiver circuits, as shown in Fig. 2. In addition to this high frequency transmitter circuits are inductively connected by means of transformers connected directly in the line circuit in series with the battery sets B and B′ in the manner described in my co-pending application, Serial Number 590,802, cited above. In this case, the condensers K and K′ are necessary in order to give a free path for the high frequency oscillations of the series connected transmitter and receiver sets T′ and R′.

Fig. 4 shows a further modification in which the battery sets B and B′ and one of the line wires such as A, are entirely eliminated, in which case I have multiplex telephony by a single wire using earth return. As is apparent from this Fig. 4, I have shown a plurality of ground branches, each including a plurality of telephone or receiver sets, each transmitter having a different frequency and having a receiver set at the other end of the line tuned to its periodicity. Also in series with the line, I have connected other transmitter and receiver sets, as shown diagrammatically at T′ and R′. In this case I am able to carry on multiplex telephony by the single wire connected to earth at various points without any cross-talk or disturbances from external causes, and I consider this an essential part of my invention. In connection with Fig. 4, I have shown means whereby Morse telegraphy may be carried on in the usual way and this without any cross interference of the messages. In case way stations are used on the line, each of such stations will be shunted by a small condenser or a condenser and inductance tuned to the frequency of the high frequency oscillations. Thus it is apparent that my invention may be superimposed directly on the present Morse telegraph systems. Other forms of high frequency transmitter and receiver circuits may be used in place of those shown, and various suitable modifications are shown and described in detail in my co-pending application, Serial Number 590,801 cited above.

Although several modifications have been described in detail in this specification, it is obvious that many changes may be made without departing from the spirit of the invention, and I therefore do not wish to be limited to the exact connections shown, but

What I claim as my invention is the following:

1. In a silent earthed multiplex telephone and telegraph system, a line wire; a plurality of earth circuits extending from said line; a plurality of transmitter or receiver circuits associated in series relation in each of said earth circuits, each transmitter circuit impressing different but ultra-sound frequencies on the line, each receiver circuit being tuned to the frequency of one transmitter.

2. In a silent earthed multiplex telephone and telegraph system, a line wire; a plurality of earth circuits extending from said line; a plurality of transmitter or receiver circuits associated in series relation in each of said earth circuits, a plurality of transmitter and receiver circuits associated in series in the line, each transmitter impressing different but ultra-sound frequencies on the line, and each receiver being tuned to the frequency of one of the transmitters.

3. In a multiplex telephone and telegraph system, a line wire; low frequency signaling apparatus connected to the line, a plurality of ground circuits extending from said line, a plurality of transmitter or receiver circuits associated in series relation in each earth connection, each trans-

mitter circuit impressing different but ultra-sound frequencies on the line, each receiver circuit being tuned to the frequency of one transmitter.

4. In a multiplex telephone and telegraph system, a pair of line wires; low frequency signaling apparatus associated therewith; a plurality of earth connections placed between each line and the earth, a plurality of high frequency signaling circuits associated in series in each earth connection, each transmitter circuit developing oscillations of different but ultra-sound frequency and each receiver tuned to one transmitter circuit.

5. In a multiplex telephone and telegraph system, a pair of line wires; low frequency signaling apparatus bridged across said lines; a plurality of earth connections placed between each line and the earth, a plurality of high frequency signaling circuits associated in series in each earth connection, each transmitter circuit developing oscillations of different but ultra-sound frequency, each receiver circuit being tuned to one transmitter circuit and containing a detector for high frequency oscillations and a telephone receiver operatively associated with said detector.

6. In a multiplex telephone and telegraph system, a pair of line wires, battery telephone sets bridged across said line wires, a plurality of earth connections placed between each line and the earth, a plurality of high frequency signaling circuits associated in series in each earth connection, each transmitter circuit developing oscillations of different frequency, each receiver circuit being tuned to one transmitter circuit and containing a detector for high frequency oscillations and a telephone receiver operatively associated with said detector.

7. In a multiplex telephone and telegraph system, a pair of line wires, battery telephone sets bridged across said line wires, a plurality of earth connections placed between each line and the earth and containing a variable condenser and a variable inductance, a plurality of high frequency signaling circuits inductively associated in series in each connection, each transmitter circuit containing a generator of high frequency oscillations, a variable condenser and inductance for tuning said circuits and a telephone transmitter for modifying said oscillations, each receiver circuit being tuned to one of the transmitter circuits and containing a detector of high frequency oscillations and a telephone operatively connected therewith.

8. In a multiplex telephone and telegraph system, a pair of line wires; battery telephone sets bridged across said line wires; a plurality of earth connections placed between each line and earth and containing a variable inductance, and variable condenser; a plurality of high frequency signaling circuits inductively associated in series in each earth connection a plurality of signaling circuits connected inductively in series in the lines, each transmitter circuit developing oscillations of different ultra-sound frequencies and containing a microphone transmitter for modifying the oscillations in accordance with speech, each receiver circuit containing a variable inductance and a variable capacity, and tuned to the frequency of one transmitter circuit, a detector in shunt to the condenser of the receiver circuit and a telephone operatively connected therewith.

9. In a multiplex telephone and telegraph system, a pair of line wires; battery telephone sets bridged across said line wires; a condenser of small capacity parallel to each of the battery telephone sets; a plurality of earth

connections placed between each line and earth and containing a variable inductance and a variable capacity, a plurality of high frequency signaling circuits inductively associated in series in each earth connection; a plurality of signaling circuits connected inductively in series in the lines, each transmitter circuit developing electric waves of different ultra-sound frequencies and containing a microphone transmitter for modifying the oscillations in accordance with speech; each receiver circuit containing a variable inductance and a variable capacity and tuned to the frequency of one transmitter circuit, a detector in shunt to the condenser of the receiver circuit and a telephone operatively connected therewith.

GEORGE OWEN SQUIER.

Witnesses:

P. I. WOLD,

E. R. CRAM.

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